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AN INVESTIGATION OF THE TRAINING AND SKILL REQUIREMENTS OF INDUSTRIAL MACHINERY MAINTENANCE WORKERS. VOLUME I. FINAL REPORT.

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DRAMATIC CHANGES IN THE CHARACTERISTICS AND COMPLEXITY OF PRODUCTION MACHINERY AND EQUIPMENT HAVE CREATED A GROWING NEED FOR ADEQUATELY TRAINED AND SKILLED MACHINERY MAINTENANCE WORKERS IN INDUSTRY. THIS STUDY DEFINED THE CHARACTERISTICS OF THE LABOR MARKET FOR MACHINERY MAINTENANCE WORKERS SUCH AS MILLWRIGHTS, MECHANICAL HYDRAULIC, ELECTRICAL, ELECTRONICS REPAIRMEN, AND WELDERS TO ASSESS THE EXTENT TO WHICH RESOURCES SHOULD BE DEVOTED TO DEVELOPING AND ESTABLISHING MACHINERY MAINTENANCE TRAINING PROGRAMS, BUT PRIMARILY IT IDENTIFIED THE SPECIFIC TRAINING AND SKILLS NEEDED BY MAINTENANCE WORKERS IN INDUSTRY. DATA AND INFORMATION WERE OBTAINED THROUGH FIELD INTERVIEWS WITH MORE THAN 100 PLANT ENGINEERS, MAINTENANCE SUPERVISORS, AND TRAINING DIRECTORS IN THE CHICAGO AREA, AND A QUESTIONNAIRE SURVEY OF MORE THAN 250 MEMBERS OF THE AMERICAN INSTITUTE OF PLANT ENGINEERS. RESULTS OF THE INVESTIGATION INDICATED THAT THE FIELD OF INDUSTRIAL MACHINERY MAINTENANCE IS PARTICULARLY SUITABLE FOR OCCUPATIONAL TRAINING. THE LABOR MARKET SIZE, DISTRIBUTION WITHIN THE ECONOMY, RATE OF GROWTH, AND EARNING POTENTIAL ALL SUGGEST THAT PERSONS TRAINED FOR THIS FIELD CAN EXPECT TO BECOME PRODUCTIVE MEMBERS OF THE INDUSTRIAL WORK FORCE. THERE IS AN IMMEDIATE NEED FOR TRAINING PROGRAMS IN HIGH SCHOOLS AND OTHER INSTITUTIONS THAT WOULD BE AVAILABLE TO ADULT WORKERS. TRAINING AND SKILL REQUIREMENTS CAN BE GROUPED INTO CLASSIFICATIONS OF BASIC MAINTENANCE, FUNDAMENTAL SPECIALIZED, AND ADVANCED SPECIALIZED TRAINING. THE SPECIFIC MATERIALS IN EACH AREA ARE INCLUDED. MOST OF THE TRAINING IS PRESENTLY PROVIDED BY INFORMAL, ON-THE-JOB TRAINING, OFTEN WITHOUT DIRECT CONTROL OR SUPERVISION. SUPPLEMENTARY AND SUPPORTING DATA STUDY ARE GIVEN IN VT 002 821. (HC)

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AN INVESTIGATION OF THE TRAINING AND SKILL REQUIREMENTS OF INDUSTRIAL MACHINERY MAINTENANCE WORKERS

Volume I

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An Investigation of the Training and Skill Requirements of Industrial Machinery Maintenance Workers

Frank Lynn
Project Director

Project No. EO 502, Bureau 5-1201
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SUMMARY OF STUDY FINDINGS AND RECOMMENDATIONS

SUMMARY OF STUDY FINDINGS AND RECOMMENDATIONS

During the last 25 years, the rapid growth of our industrial economy has brought about dramatic changes in the characteristics and complexity of production machinery and equipment. These changes have created a growing need for adequately trained and skilled machinery maintenance workers in industry. However,. little effort has been devoted to developing and instituting maintenance training programs either in industry or in our public educational systems. Recognizing that a portion of the training requirements for the machinery maintenance field could be provided in adult, secondary school and post secondary vocational training, the Division of Adult and Vocational Research of the U.S. Office of Education provided support for this research study. The primary objective of this investigation was to identify the specific knowledge, skill, and training required of occupations within the machinery maintenance field and to determine how these requirements might change in the foreseeable future. The findings and conclusions of this study are summarized in this portion of the report.

I. THE LABOR MARKET FOR INDUSTRIAL MACHINERY MAINTENANCE WORKERS

One facet of this research study was concerned with defining the characteristics of the labor market for machinery maintenance workers (i.e. mechanical repairmen, millwrights, hydraulic repairmen, electricians and electronic repairmen). This market is a most important consideration in assessing the extent to which resources should be devoted to the development and establishment of machinery maintenance training programs. The results of this aspect of the investigation indicate that the field of machinery maintenance has a number of characteristics which make it a particularly attractive area for occupational training:

1. Machinery maintenance workers are found in every facet of our nation's industrial economy and, as a result, a labor market for these maintenance workers exists in virtually every industrial area of the nation.

2. With a labor force estimated at 400,000 to 450,000 workers, the machinery maintenance field appears to be of sufficient size to justify undertaking the development and establishment of maintenance training programs.

3. Wage levels in the machinery maintenance occupations are more than adequate with the total income potential probably higher than in any other hourly-wage occupation in industry.

4. Industry's needs for adequately trained maintenance workers has become a critical problem; according to published surveys as many as 79% of the companies questioned indicate they are presently experiencing a shortage of skilled maintenance personnel.

5. The machinery maintenance workforce is expected to increase at a faster rate than the overall rate of growth for production worker employment, with 25,000-35,000 new job openings being created in this field each year during the next 3-5 years.

Based on these considerations, it is evident that the field of machinery maintenance training is a fruitful area for occupational training and one in which effort should be exerted to expand the scope and the effectiveness of present training activities.

II. TRAINING AND SKILL REQUIREMENTS

The primary focal point of this entire study was concerned with the identification of the specific training and skills needed by maintenance workers in industry. Data and information concerning these requirements were obtained through field interviews with more than one hundred plant engineers, maintenance supervisors, and training directors in the Chicago area, followed by a questionnaire survey of more than 250 members of the American Institute of Plant Engineers. The results of this investigation indicate that the training and skill requirements of machinery maintenance workers can be grouped into three classifications --- basic maintenance training, fundamental specialized training, and advanced specialized training. The specific material included in each of these areas is shown in the "Machinery Maintenance Training Tree" contained within the report.

Many of the basic training subjects which are required by machinery maintenance workers also appear to apply to other maintenance occupations (e.g., as appliance repairmen, automotive mechanics, etc.), which encompass approximately five million workers throughout business and industry. Furthermore, basic maintenance training and some of the fundamental specialized training is particularly suitable for vocational and adult educational programs. A detailed listing and explanation of the individual training and skills required of each machinery maintenance occupation is presented in the report.

III. EXISTING MAINTENANCE TRAINING PROGRAMS

This research study was also concerned with evaluating existing maintenance training programs and comparing their content with the maintenance training and skill requirements defined previously in this investigation. Despite the wide agreement among plant engineers, maintenance supervisors and industrial training directors as to the need for better and more effective maintenance training, most of the training in this field is presently provided by informal, on-the-job training, often without any direct control of supervision. At the present time, formal training activities (apprenticeship programs and trade schools) are provided to only a small portion (15-25%) of the employees entering the maintenance workforce, but their role should increase as a growing technical sophistication of production machinery makes formal training a much more important consideration for new maintenance workers. However, since it is estimated that 30-50% of new maintenance workers now enter the workforce as adults with no experience or formal training in this field, there is an immediate need for machinery maintenance training programs in night schools and other sources that would be available to adult workers.

An inventory of formal machinery maintenance training programs indicates that more time is devoted to on-the-job training than can be reasonably justified. A 2-3-year formal training program appears to be more adequate for most maintenance occupations that the 4-year program commonly found in industry today. In addition, many of these formal programs include related classroom instruction in subjects such as engineering drawing and drafting which appear to be unnecessary for most maintenance occupations.

IV. FUTURE CHANGES IN MAINTENANCE TRAINING AND SKILL REQUIREMENTS

A portion of this study was devoted to outlining, to the extent possible, some developments likely to affect machinery maintenance training and skill requirements in the future. Hopefully, this information can be used by schools and industry training directors in providing training that is needed today and that will also reflect future maintenance training and skill requirements. It appears that several important changes will be occurring in industry's future maintenance operations ...

... electronics and hydraulics will become increasingly important areas of technical knowledge and training.

... the role of diagnostic and trouble-shooting skills in training will grow in importance in machinery maintenance operations.

... present maintenance procedures in which one individual performs all steps of the repair of machinery and equipment will eventually be broken into three separate functions --- diagnosis, replacement and repair --- that will be performed by different types of individuals having different levels of training and skills within the maintenance workforce.

... the multi-skill machinery maintenance specialist will have a limited role in industry's workforce but a new occupation --- the maintenance technician --- will emerge to provide specialized diagnostic and trouble-shooting capabilities that are becoming an increasingly important part of industry's machinery maintenance activities.

V. CONCLUSIONS AND RECOMMENDATIONS

The results of this investigation have indicated that the field of industrial machinery maintenance is particularly suitable for occupational training. The characteristics of the labor market for machinery maintenance --- its size, distribution within our economy, rate of growth and earnings potential --- all suggest that persons trained for this field can expect to become productive members of our industrial workforce. Furthermore, it is an area in which training is becoming increasingly more critical though sources of needed training are inadequate. Little formal training presently is being provided by schools and institutions despite the fact that certain facets of training appear to be best provided by these organizations. Even industry's role in maintenance training leaves much to be desired since most industry training is presently provided through unstructured, on-the-job training.

It is evident that a number of problems presently exist which must be overcome before occupational training in the machinery maintenance field can be expected to supply industry's growing needs for adequately trained workers. The magnitude of these problems and recommendations concerning possible solutions to these problems are outlined below:

1. The most critical problem in the field of machinery maintenance training is the lack of adequate training materials available to schools, industry and private organizations interested in providing this training. To resolve this problem it is strongly recommended that a "vehicle" be created through private and/or federal funding, to acquire the vast reservoir of training materials which have been developed by private industry for its own use and to make these materials available to public and private training organizations.

2. A serious need exists for the development of training curriculum in this field to provide guidance to public and private organizations in the establishment of machinery maintenance programs. These materials can and should be developed as part of the U.S. Office of Education's activities in the vocational and adult training field. In conjunction with curriculum development, a concerted effort should be made to develop comprehensive career guidance materials for distribution to vocational training schools and institutions throughout the country to stimulate the interest of both instructors and students in the career opportunities in the machinery maintenance field.

3. Private industry and vocational schools should be exposed to the findings of this investigation concerning the training and skill requirements of machinery maintenance personnel. This exposure can be provided most effectively through a joint venture of the American Institute of Plant Engineers, the Midwest Institute for Research and Training and the U.S. Office of Education in which a series of conferences and training seminars would be presented in various industrial centers of the country

4. Formal maintenance training programs now being offered in schools and industry should be evaluated to establish the steps that can be taken to make these programs more responsive to the specific training and skill requirements of the machinery maintenance field outlined in this report. Also, the normal age restrictions on formal training programs should be waived to provide an opportunity for older workers to enter the machinery maintenance workforce.

Hopefully, the results and recommendations of this study will increase the amount of machinery maintenance training presently being provided and raise the level of effectiveness of the programs now in existance. The extent to which these two objectives can be attained will largely determine the contribution which this research study makes to the continued growth of our nation's economy and to providing individuals with the training and skills that will enable them to become useful, productive members of our industrial society.

CHAPTER ONE

INTRODUCTION

INTRODUCTION

The problem of an adequately trained maintenance workforce is a by-product of our increasingly more complex industrial economy. At one time, the maintenance and repair of production machinery and equipment was the responsibility of skilled artisans and craftsmen that operated this equipment. The advent of the Industrial Revolution, with its segregation and simplification of individual tasks in the manufacturing process, created a need for individuals who specialized in the maintenance and repair of production machinery. However, since this equipment was relatively uncomplicated, a machinery maintenance worker typically needed little formal training and normally was characterized by an aptitude for "tinkering" with machinery. It is interesting to note that many of these early machinery maintenance workers received their initial training and practical experience through repairing automobiles and farm machinery when frequent breakdowns were common and "repair shops" were unknown.

During the last 25 years, the rapid growth in our industrial economy has caused a dramatic change in the characteristics and complexity of production machinery and equipment. Machinery designers and builders have been required to produce equipment that ...

... is capable of high rates of output and can handle a wide range of product variations.

... includes automatic control and measurement devices to monitor and maintain quality standards.

... reduces labor requirements by incorporating complex material handling devices and equipment.

... integrates individual machines into elaborate production line systems in which the reliability and performance of each unit affects the operation of the entire system.

These demands have resulted in new developments in machinery technology which have introduced sophisticated mechanical, electrical, hydraulic, pneumatic and electronic concepts into the design and engineering of production machinery and equipment. As a result, the traditional "hammer and wrench" mechanic and the "screwdriver" electrician are no longer capable of maintaining and servicing the modern production machinery now used in industry. Maintenance personnel are required who have training not only in the basic technical skills of machinery maintenance and repair, but also in procedures for quickly identifying the source of trouble when a breakdown occurs. In a modern manufacturing operation where the breakdown of a single piece of equipment may idle a complete production line and the cost of lost production time may exceed $20.00 per minute, maintenance workers who can quickly isolate the source of the breakdown, correct the problem and return the equipment to operation are a valuable and needed asset.

Despite the growing need for adequately trained and skilled machinery maintenance workers in industry, it appears that very little effort has been directed toward developing and instituting maintenance training programs in industry or our educational system. Although some large companies have established their own maintenance training programs, most maintenance training is provided through informal, on-the-job training efforts. It has become increasingly more evident that this traditionally informal approach to maintenance training will not satisfy industry's requirements for trained and skilled maintenance personnel. In acknowledging the critical nature of this problem, the American Institute of Plant Engineers recently established a special training committee to foster maintenance training programs in industry and in schools (See Appendix A).

Although adequate maintenance training encompasses highly sophisticated areas of mechanics, hydraulics, pneumatics and electronics, it must be preceded by fundamental training in basic concepts in these same areas of machine maintenance technology. Recognizing that much of this fundamental training could be provided by adult, secondary school and post-secondary vocational training programs, the Division of Adult and Vocational Research of the U.S. Office of Education provided support for this research study of the training and skill requirements of industrial machinery maintenance workers. The objective of this research program was threefold:

1. To determine if a sufficient degree of commonality of knowledge, skill and training requirements exists among machinery maintenance workers throughout industry to permit the establishment of additional maintenance training courses and programs by educational institutions and/or industry.

2. To identify in detail the specific knowledge, skill and training requirements of individual occupations within this machinery maintenance field.
3. To examine future developments in machinery technology to determine the impact they will have on the knowledge, training and skill requirements of industrial machinery maintenance workers.

As this research investigation progressed, it became increasingly more evident that this study could accomplish a fourth, and perhaps more important objective by acting as a catalyst to initiate action by industry, schools and other organizations to provide immediate action on this problem of maintenance training. In this regard, the Midwest Institute For Research and Training is currently working with the American Institute of Plant Engineers, the U.S. Office of Education, several state and local educational groups and with private industry to foster machinery maintenance training and to resolve some of the major obstacles that are hindering further efforts in this field.

* * * * * * *

This report presents the findings and conclusions of this study of the training and skill requirements of industrial maintenance workers in terms of . . .

- the nature of the labor market for maintenance workers.
- the training and skill requirements of individual occupations within the maintenance field.
- an evaluation of the maintenance training programs now in existence in industry and in vocational training schools.
- future developments in machinery technology and their impact on maintenance training requirements.
- an assessment of the major obstacles inhibiting the establishment of effective maintenance training programs and recommendations concerning steps that could and should be undertaken to overcome these problems.

It is expected that this report will be used widely by both industry and educational institutions in helping to establish or improve maintenance training programs. Therefore an effort has been made to present these findings in such a manner that they will be useful both to an industrial training director attempting to establish an extensive apprenticeship maintenance training program and to a vocational school administrator establishing an introductory program in industrial maintenance. Furthermore, this report is intended to provide direction and guidance to individuals and organizations interested in increasing the effectiveness of maintenance training programs now in existence and in expanding the scope of training activities in this field of occupational training. To the extent that this report and the research efforts that preceded it satisfy these objectives, this investigation will have made an important contribution toward resolving this increasingly critical aspect of industry's manpower needs and upgrading the effectiveness of occupational training both in the schools and in industry.

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CHAPTER TWO

THE LABOR MARKET FOR INDUSTRIAL MACHINERY MAINTENANCE WORKERS

THE LABOR MARKET FOR INDUSTRIAL MACHINERY MAINTENANCE WORKERS

Although the primary purpose of this research study was to determine the training and skill requirements of machinery maintenance workers in industry, these findings would be incomplete without some assessment of the labor market for these occupations. Such factors as the number of individuals working in these fields, the rate at which new job opportunities are becoming available, the wage levels that prevail in these occupations and the demand for trained and skilled maintenance workers are important considerations in evaluating the extent to which public and private organizations should expend their resources to provide adequate training programs in the maintenance field. This chapter provides some answers to these questions concerning the characteristics of the labor market for industrial machinery maintenance workers.

I. THE DISTRIBUTION OF THE LABOR MARKET FOR MAINTENANCE WORKERS

One of the major reasons why industrial machinery maintenance has largely gone unrecognized as an area in which adequate training has become a critical problem is that it is a horizontal occupational field that cuts across all of industry. Maintenance workers are found in virtually every industrial facility in the country, rather than being concentrated in a single industry or small group of industries. Not only are maintenance workers found in manufacturing plants, but also in warehouses and other installations which use conveyors and other types of industrial machinery in their operations. However, since the maintenance workforce is normally small in comparison to total plant employment, the need for trained maintenance workers is not always readily apparent.

Although the diffused nature of maintenance workers throughout industry makes it difficult to identify this labor market, it also makes the maintenance field an attractive opportunity for occupational training. Individuals with maintenance training can expect to find employment opportunities in every industry and in almost every area of the country. However, since maintenance work is directly related to industrial activity, employment opportunities for maintenance workers are primarily located in heavily industrialized centers of the country such as Chicago, Detroit, Cleveland and New York. As a result, any major effort directed toward encouraging the development and establishment of training programs in industrial machinery maintenance should probably be concentrated in these industrial areas in order to be most effective.

II. THE SIZE AND STRUCTURE OF THIS MAINTENANCE LABOR FORCE

The maintenance workforce in a typical manufacturing plant encompasses a wide variety of different occupations, with an equally wide variation in training and skill requirements. In large industrial plants, the size of the maintenance workforce, combined with labor contract restrictions, generally results in a high degree of job specialization of maintenance tasks. In smaller plants, specialization is generally not feasible and maintenance workers are expected to perform a number of different maintenance functions. In general, industry's maintenance workforce can be grouped into five classifications on the basis of the type of work they perform:

1. Administrative and Clerical Workers

Maintenance activities are no different than other facets of industry's operations with respect to the need for administrative and clerical personnel. The maintenance workforce is ordinarily under the supervision of the Plant Engineer or Maintenance Foreman who may have one or more administrative assistants, depending upon the size of the maintenance workforce and the number of shifts normally worked at the plant. Clerical workers perform normal "paperwork" activities and may help to administer certain specialized maintenance support activities such as purchasing and operation of tool cribs. These administrative and clerical workers are estimated to comprise 12-15% of the total maintenance workforce.

2. Custodial Workers

Custodial workers are normally only concerned with general janitorial and housekeeping activities --- cleaning floors, emptying trash containers, washing windows, etc. These jobs require only a minimum of skill or training and are the lowest category of maintenance work in terms of wage levels and of desirability. Custodial workers probably constitute no more than 8-10% of the maintenance workforce.

3. Building Maintenance Workers

Building maintenance is normally performed by individuals in highly specialized trades or occupations. In a typical large industrial plant, this building maintenance workforce might include carpenters, pipefitters, roofers, stationary engineers (who operate the plant's boiler and heating systems) and plumbers. Smaller industrial plants tend to contract many of these building maintenance activities to outside firms specializing in these field and, therefore, have fewer building maintenance workers on their payroll. It is estimated that approximately 15% of the total maintenance workforce is involved in these building maintenance activities.

4. Maintenance Machinists and Diemakers

Since machinery components and parts continually have to be repaired or replaced due to wear or breakage, many industrial plants maintain a separate group of machinists and diemakers to fabricate, machine and repair these parts and dies when required. Maintenance machinists and diemakers are normally highly skilled individuals who have completed apprenticeship programs in their fields and are capable of operating a wide variety of machine tools. It became evident from the field interviews conducted during this investigation that some maintenance machinists actually function as both machinists and machinery repairmen. This situation appears to be particularly common in small industrial plants where specialized maintenance functions are impractical.

Because of this overlap of maintenance functions, it is difficult to estimate the number of maintenance machinists and diemakers in the maintenance workforce. This problem is further complicated by the fact that maintenance machinists and diemakers often are not differentiated from machinists and diemakers engaged in manufacturing activities (e.g., the production of tools and dies). However, based on fragmentary data, it is estimated that maintenance machinists and diemakers probably constitute 15-20% of the total maintenance workforce.

5. Machinery Maintenance Workers

Machinery maintenance workers are those individuals who are primarily concerned with the servicing and repair of industrial production machinery and equipment. This group normally includes mechanical repairmen, millwrights and electricians and maintenance specialists in the fields of hydraulics, electronics and instrumentation. Machinery maintenance workers, who are the primary subject of this investigation, constitute the largest occupational group within the maintenance field, comprising an estimated 40-50% of the total maintenance workforce.

The most difficult aspect of defining the size and structure of the maintenance workforce is estimating the number of individuals that are employed in these occupations. The Bureau of Labor Statistics of the U.S. Department of Labor does not segregate maintenance occupations in its industry and manpower surveys. In addition, since the maintenance workforce is so diffused throughout industry, it is difficult to ascertain the size of this workforce. Furthermore, the relationship between the size of the maintenance workforce and total plant employment varies significantly from one plant to another. For example, in continuous process industries (e.g., steel mills, chemical plants and oil refineries) where equipment requirements are substantial and the automated nature of the manufacturing process reduces production worker requirements, the maintenance workforce may comprise 20-30% of total plant employment. In other industries where production equipment requirements are low and labor requirements are high (e.g., electronic assembly), maintenance workers may account for less than 5% of total plant employment.

Both the size of industry's maintenance workforce and the number of job openings in each of the maintenance occupations under investigation in this study are important considerations in determining the amount of effort and resources that should be devoted to maintenance training. Therefore, an effort has been made to develop reasonable estimates of the approximate size of this maintenance workforce and the number of individuals presently employed in the particular maintenance occupations that are of interest to this study. A number of recent surveys provide a starting point for the development of these estimates. One survey of industrial maintenance practices in 309 plants conducted by Mr. Efraim Turban and published in Factory (28) indicated that these plants had an average of 9.4 maintenance for every 100 production workers (8.6% of total production employment). This estimate is corroborated to some extent by a special survey of industry's maintenance costs made by the U.S. Department of Commerce, Bureau of the Census (1). This survey revealed that industry's maintenance payroll at that time accounted for 5.7% of industry's total payroll, or 7.6% of the payroll of all production workers. A third survey of the maintenance practices of more than 400 industrial plants (encompassing 187,000 employees) conducted by Factory (36) in 1965 indicated that the total maintenance workforce (including supervisors and clerical workers) accounted for 11.2% of total plant employment. Based on this fragmentary data, it is estimated that in 1966 approximately 1.0 - 1.2 million individuals were employed in industry's maintenance workforce. The distribution of this laborforce by type of maintenance activity is shown in Exhibit I.

Since this investigation is primarily concerned with the training and skill requirements of machinery maintenance workers, it was also necessary to estimate the number of workers employed in each of the individual occupations within this segment of the maintenance workforce. These estimates are also shown in Exhibit I. They indicate that approximately 240,000-260,000 workers are involved in mechanical aspects of machinery repair and maintenance (mechanical repairmen and millwrights), and an additional 5,000-10,000

Exhibit I

ESTIMATED DISTRIBUTION OF EMPLOYMENT IN INDUSTRY'S MAINTENANCE WORKFORCE -- 1966

TYPE OF MAINTENANCE ACTIVITY	NUMBER OF EMPLOYEES (1966)
Administrative and Clerical Workers	170,000 - 180,000
Custodial Workers	120,000 - 130,000
Plant Maintenance Workers	170,000 - 180,000
Maintenance Machinists and Diemakers	200,000 - 225,000
Machinery Maintenance Workers	
. Mechanical Repairmen and Millwrights	240,000 - 260,000
. Hydraulic Repairmen	5,000 - 10,000
. Electricians	140,000 - 150,000
. Electronic and Instrument Repairmen	25,000 - 40,000
TOTAL MAINTENANCE WORKFORCE	1,000,000 - 1,200,000

Source: Midwest Institute for Research and Training
U.S. Department of Labor, Occupational Outlook Handbook, Bulletin No. 1450, U.S. Government Printing Office, Washington, D.C., 1966.

individuals are currently employed as specialists in the repair and servicing of hydraulic equipment.

Machinery repairmen and millwrights have been grouped together in these estimates because the differentiation between mechanical repairman and millwright is particularly difficult to establish from industry data because considerable ambiguity exists in the usage of this terminology. For the purposes of this investigation, mechanical repairmen are defined as being concerned with the servicing and repair of mechanical components of production machinery; whereas, millwrights are defined as those individuals who are concerned with the erection and installation of new machinery and equipment. Since the term "millwright" at one time encompassed both of these maintenance functions and this traditional terminology is still used in some companies, it is difficult to obtain valid employment data for these two maintenance occupations. However, this differentiation appears to be unimportant for the purposes of this investigation since it appears that the training and skill requirements of these two maintenance occupations are very similar (See Chapter III). In addition to individuals who are specifically involved in mechanical repair and maintenance work, it is estimated that a portion of industry's 60,000 maintenance machinists are engaged in machinery maintenance and repair activities. As these projections also indicate, an estimated 140,000-150,000 individuals work as maintenance electricians and 25,000-40,000 workers specialize in electronic and instrument maintenance activities. In total, it is estimated that 400,000-450,000 individuals in industry are currently working in the machinery maintenance occupations that are the subject of this investigation.

III. INCOME POTENTIAL FOR MAINTENANCE WORKERS

The field of machinery maintenance probably has a higher income potential than any other "blue collar" occupational field in industry. The Occupational Outlook Handbook (12) lists the range of hourly wage levels for the major machinery maintenance occupations as:

Mechanical Repairmen:	$2.20 - $3.59/hr.
Electricians:	$2.18 - $3.64/hr.
Millwrights:	$2.66 - $4.83/hr.

However, these wage rates substantially understate the income potential for machinery maintenance workers. Since major maintenance and repair-work on production machinery generally takes place after working hours, and on weekends, holidays and during vacation periods, machinery maintenance workers have more than ample opportunity to supplement their normal weekly wages through overtime earnings. Key maintenance workers are often able to obtain as much overtime work as they are willing to undertake. As a result, during the field survey it was not unusual for plant engineers to state that the annual wage earnings of their key maintenance workers exceeded $12,000 per year and, in many instances, these maintenance workers were the highest paid hourly employees in the plant. From these comments and observations, it is evident that the field of machinery maintenance provides more than adequate income potential to individuals who are working in this field.

IV. JOB OPPORTUNITIES IN THE MACHINERY MAINTENANCE FIELD

Because machinery maintenance is considered one of the prestige occupations in industry's production labor force and offers one of the highest income potentials for hourly wage earners, the workforce in this field tends to be relatively stable. For example, Dow Chemical Company has an annual turnover of only 5% of its maintenance workforce. One of the primary reasons for this low labor turnover is the fact that machinery maintenance jobs are normally terminal occupations with no natural avenues of progression available to these workers to move into other occupations or positions. Even the limited number of opportunities available to maintenance workers for promotion into supervisory positions as plant engineers or maintenance foremen are diminishing rapidly as industry increasingly is turning to college-trained engineers to fill these positions.

As a result of this stability, job openings in the machinery maintenance field result primarily from replacement needs (i.e., persons who retire or leave the maintenance field for other reasons) and new job-openings created by the growth of our industrial economy and the installation of more complex, automated equipment requiring more maintenance. The impact which these latter two factors, economic growth and the installation of more automated machinery, have on industry's requirements for new machinery maintenance workers is the subject of considerable controversy, since little data exists concerning industry's historical maintenance requirements. One indication of the relative growth of the maintenance workforce can be obtained from a comparison of occupational information for the years 1950 and 1960 obtained from the U.S. Bureau of the Census. This data indicates that in this ten-year period the number of maintenance electricians in industry increased 29.5%; during this same period, the number of millwrights in industry increased 9.9%. In comparison, the total number of production workers in industry increased only 3.7% from 1950 to 1960.

Since millwright is the occupational group in the maintenance field which is growing at the slowest rate, it is evident that the demand for maintenance workers is increasing at a considerably more rapid rate than that of industry's production workforce. Based on this limited data, it is estimated that the machinery maintenance labor force increased 3-4% per year during the period 1960-1965 and that this rate of growth will continue or increase slightly during the next 5 years -- assuming no major disruption in the growth of the nation's industrial economy during this period. The combination of growth in the overall size of industry's machinery maintenance workforce and the need to replace maintenance workers who have retired or left the labor force suggests that an estimated 25,000-35,000 new machinery maintenance workers probably will be needed by industry each year during the next 5 years. The estimated distribution of these job-openings among the individual machinery maintenance occupations is shown in Exhibit II.

Exhibit II

ESTIMATED ANNUAL JOB OPENINGS IN THE MAINTENANCE OCCUPATIONS
1965 - 1970

MACHINERY MAINTENANCE OCCUPATION	NUMBER OF JOB OPENINGS PER YEAR
Machinery Repairmen & Millwrights	12,000 - 15,000
Hydraulic Repairmen	1,000 - 2,000
Maintenance Electricians	10,000 - 15,000
Electronic and Instrument Repairmen	2,000 - 3,000
Total Machinery Maintenance Workforce	25,000 - 35,000

Source: Midwest Institute for Research & Training

One final question regarding employment opportunities in this field that had to be answered to the extent possible in this research study concerns the demand for trained machinery maintenance workers. It would be a waste of vital resources to invest time and money to provide machinery maintenance training if this training were unnecessary. One indication of the critical need for adequately trained maintenance workers is provided by the findings of two surveys of plant engineers and maintenance supervisors. Four years ago the American Institute of Plant Engineers conducted a survey (31) that indicated that 3 of the 6 most critical problem areas in the industrial maintenance field were directly related to the training and skill requirements of machinery maintenance workers. More recently, Mill & Factory (43) magazine's report on maintenance training indicated that 79% of the plants surveyed were experiencing a shortage of skilled maintenance workers, with the greatest need being in the maintenance occupations that are the subject of this study. The magnitude of this shortage is indicated by the fact that most of these plants were experiencing more than a two-month delay in finding skilled maintenance workers to fill vacancies in their labor force. A similar response concerning the unavailability of adequately trained maintenance workers was obtained from the personal interviews conducted with plant engineers during this investigation. Based on this information, it is evident that a serious need exists for trained maintenance workers and that individuals receiving adequate training should encounter no serious difficulty finding employment within the maintenance field.

V. SOURCE OF NEW MAINTENANCE WORKERS

One valuable by-product of the survey of plant engineers conducted during this investigation (See Appendix B) is the information generated concerning the source of new employees for industry's machinery maintenance workforce. This information, which is summarized in Exhibit III, shows the extent to which industry's present needs for trained maintenance workers are not being met through normal occupational training channels. As this chart indicates, nearly one-half of the supply of new maintenance workers comes from "off-the-street hiring." Undoubtedly, the majority of these individuals obtained in this manner are skilled maintenance workers who have been hired away from other companies, but personal interviews suggested that a significant portion of these individuals have no prior experience or training in the machinery maintenance field and are hired for their aptitude or interest in this type of work. An additional 25-30% of new maintenance workers are obtained through the upgrading of production workers in the maintenance workforce. Apprenticeship training programs contribute approximately 10-15% of industry's new maintenance workforce, trade schools

Exhibit III

SOURCE OF INDUSTRY'S NEW MAINTENANCE WORKERS

Size of Maintenance Workforce / Source of New Maintenance Workers	LESS THAN 40 WORKERS	40 - 100 WORKERS	MORE THAN 100 WORKERS	TOTAL FOR ALL PLANTS
OFF-THE-STREET HIRING	40 - 45%	40 - 45%	45 - 50%	45 - 50%
PRODUCTION WORKERS	30 - 35%	25 - 30%	25 - 30%	25 - 30%
APPRENTICESHIP TRAINING PROGRAMS	5 - 10%	15 - 20%	15 - 20%	10 - 15%
TRADE SCHOOLS	5 - 10%	5 - 10%	5 - 10%	5 - 10%
OTHER SOURCES	10 - 15%	5 - 10%	0 - 5%	5 - 10%

Source: Midwest Institute for Research & Training

only 5-10%, and the remaining 5-10% are obtained from other sources such as the Armed Forces.

The role of the production workforce in supplying 25-30% of new maintenance employees is paradoxical in light of industry's concern for adequately trained maintenance workers. One major reason for this apparent anomaly between industry's maintenance training needs and its hiring practices is caused by union contract provisions dealing with employment opportunities in the maintenance field. In many companies interviewed, union contracts specify that job-openings in the maintenance workforce must first be made available to production workers who satisfy the minimum job qualifications before anyone from outside the company can be hired. A second reason for this conversion of production workers into maintenance workers arises in smaller plants where the production worker may become sufficiently familiar with the machinery with which he works that he can be readily taught how to maintain and service this equipment. (However, this type of individual is likely to be unable to adapt to the maintenance requirements of more sophisticated equipment.) This conclusion is confirmed by the table in Exhibit III which indicates that production workers constitute 30-35% of the supply of new maintenance workers in small plants vs. 25-30% in medium and large plants.

This data on the source of new machinery maintenance workers for industry also provides a valuable insight into the areas in which maintenance training should be implemented to resolve the immediate and long-range needs of this field. Since perhaps 30-50% of the individuals now entering the maintenance workforce (production workers plus some off-the-street hiring) have no formal training in these occupational skills, immediate emphasis should be placed on adult occupational training programs rather than high school apprenticeship and trade school vocational training. Although concentration on adult occupational training (e.g., night school, adult education and joint school-industry programs) will help to satisfy immediate needs for more adequately trained maintenance workers, it is only an interim solution to the overall maintenance training problem.

It is our opinion that the present patterns of new employee recruitment for the maintenance workforce will change substantially during the next 5-10 years. As industry becomes more convinced of the importance of adequately trained maintenance workers, it will be forced to alter both its procurement procedures and its training activities. The result is expected to be an increase in the number of new maintenance employees that are obtained from vocation schools, junior colleges, trade schools and formal apprenticeship programs. Even those new employees that are obtained from the production workforce are likely to have to undertake some formal training through joint school-industry programs. Therefore, the long-range effort in the field of maintenance training should be directed toward programs in the vocational training field as well as a continuing effort in adult occupational training. A more detailed discussion of this subject is presented in subsequent sections of this report.

* * * * * * *

This portion of the report provides a frame of reference from which the U.S. Office of Education and other interested organizations can realistically evaluate the feasibility of investing resources in the development and establishment of training programs in the machinery maintenance field. As this discussion indicates, the field of machinery maintenance has a number of characteristics which make it a particularly attractive area for occupational training:

1. Machinery maintenance workers are found in every facet of our industrial economy and, as a result, a labor market for maintenance workers exists in any area or community throughout the country having a substantial amount of manufacturing activity.

2. The machinery maintenance labor force is estimated at 400,000-450,000 workers which is of a sufficient size to warrant the development and establishment of maintenance training programs both in industry and schools.

3. The wage levels in the machinery maintenance occupations -- mechanical repairman, millwright, hydraulic repairman, electrician and electronic repairman -- are more than adequate and the total income potential (including overtime pay) is probably higher than in any other hourly wage occupation in industry.

4. Industry's needs for adequately trained maintenance workers has become a critical problem; according to published surveys as many as 79% of the companies surveyed indicate that they are presently experiencing a shortage of skilled maintenance personnel.

5. Formal training activities (apprenticeship programs and trade schools) are provided to only a small portion, 15-25%, of new employees entering the maintenance workforce, but their role should increase as the growing technical sophistication of production machinery makes formal training a much more important consideration for new maintenance employees.

6. The machinery maintenance workforce is expected to increase at a faster rate than the overall rate of growth of production worker employment and, in combination with replacement requirements, will result in the creation of 25,000-35,000 new job openings per year during the next 3-5 years.

7. Since an estimated 30-50% of the new employees enter the maintenance workforce as adults with no background or formal experience in this field, there is an immediate need for training programs in night schools and joint industry-school programs that would be available to adult workers.

CHAPTER THREE

TRAINING AND SKILL REQUIREMENTS

TRAINING AND SKILL REQUIREMENTS

Having defined the characteristics of the labor market for industrial machinery maintenance workers, the next and most important aspect of this research study concerns the specific training and skill requirements of individual occupations within this maintenance field. The occupations covered are mechanical repairman, hydraulic repairman, millwright, electrician, electronic repairman, and welder. This chapter describes the method used to determine the training requirements for each of these occupations, defines these requirements, and considers the significant commonality of training requirements for all of these maintenance occupations. The "Machinery Maintenance Training Tree" was developed to graphically present these findings and to provide a basic structural outline for maintenance training programs. Other considerations which are also critical to an understanding of the training and skill requirements of machinery maintenance workers are also discussed.

I. METHOD OF DETERMINING TRAINING AND SKILL REQUIREMENTS

From a survey of existing maintenance programs, both in industry and in the schools (See Chapter IV), it quickly became evident that very few formal machinery maintenance programs are presently in existence except in a few large companies. Furthermore, the training programs have a wide variation both in subject material and in the amount of training provided. On the basis of these findings, it was evident that this investigation would have to devote considerable time and effort to determining what machinery maintenance workers need to know in order to develop valid conclusions and recommendations concerning maintenance training programs.

The primary sources of data and information on these maintenance training and skill requirements were plant engineers, maintenance supervisors, and training directors in industry. The judgment and evaluation of these maintenance supervisors and plant engineers were considered to be particularly pertinent since they ....

. . . . have a detailed knowledge of the maintenance requirements and skills necessary to effectively service and repair the production machinery and equipment in their plant.

. . . . have the primary responsibility for hiring machinery maintenance workers and assessing the informal or formal training these individuals need to adequately perform necessary maintenance functions.

. . . . are likely to provide a pragmatic picture of industry's needs and the type of maintenance training and skills required to meet these needs.

To obtain the data and information required to define these training and skill requirements, the Midwest Institute for Research and Training elicited the cooperation and assistance of the American Institute of Plant Engineers (AIPE) in this undertaking. From their membership list, 150 plant engineers and maintenance supervisors in the Chicago Area were selected for in-depth personal interviews dealing with the training and skill requirements of their machinery maintenance employees. These interviews were structured so as to provide a representative sample of manufacturing plants in various industries and various levels of employment. (A more comprehensive discussion of this survey methodology is presented in Appendix B.) The objectives of this in-depth interviewing were threefold:

1. To evaluate the extent to which these plant engineers and maintenance supervisors are able to define the training and skill requirements of their maintenance workers.

2. To obtain an insight into some of the important qualitative aspects of maintenance training (e.g., the extent to which industry needs multi-skilled craftsmen in the machinery maintenance field).

3. To develop, test, and refine a questionnaire that could be used to survey similar individuals in industrial plants throughout the country.

On the basis of approximately 70 field interviews, a questionnaire listing 117 areas of potential maintenance training and skills was compiled (See Appendix B). The subjects were grouped into eight major categories --- blueprint reading, mathematics, measurement, mechanics, hydraulics, electrical and electronics, pneumatic, and miscellaneous subject areas such as safety, welding and pipefitting. For each maintenance occupation, the plant engineer or maintenance supervisor was asked to indicate which subject areas he felt an accomplished maintenance worker should know to adequately maintain the machinery and production equipment in his plant. The maintenance occupations encompassed in this survey were:

- Mechanical Repairman
- Hydraulic Repairman
- Millwright
- Electrician
- Electronic Repairman
- Welder

Welders were included in this survey primarily because some industrial plants (particularly in the chemical, oil and steel industries) indicated that welders were a significant occupational group within their maintenance workforce. Another important occupational area, instrument repairman, was deliberately excluded from this survey since a comprehensive study of the training and skill requirements in this field was already being undertaken by the Instrument Society of America. The survey questionnaire was mailed on a random basis to approximately 1600 plant engineers, maintenance supervisors and building superintendents who are members of the American Institute of Plant Engineers. A total of 263 questionnaires (16%) were returned by individuals directly concerned with the supervision of maintenance workers.

II. THE "MACHINERY MAINTENANCE TRAINING TREE"

The data obtained from this survey was analyzed to determine . . . .

- . . . . the extent to which each of these subject areas is applicable to all of the maintenance occupations under investigation (i.e., horizontal coverage).
- . . . . a quantitative measure of the relative importance of each of these subject areas within a given maintenance occupation (i.e., vertical coverage).

This analysis provides a quantitative measure of the value ("Measure of Effectiveness") of a subject to workers in each particular maintenance occupation. For example, from Exhibit VI, we see that an ability to read scale drawings (classified under "Blue Print Reading") is considered necessary for welders by 83% of those surveyed. Thus, the subject, "Reading Scale Drawings," has a Measure of Effectiveness of 83% for the welding occupation.

This quantitative Measure of Effectiveness is of particular value to training directors, vocational educators and others who are directly concerned with the establishment of maintenance training programs and the development of curriculum and course materials for these programs. It provides a method to quantitatively assess alternatives which are ordinarily not available in the planning and development of most training programs and, as a result, much of this evaluation is normally done intuitively or by personal judgment. This quantitative Measure of Effectiveness can be used in a number of ways to "tailor" a maintenance training program to specific time limitations and training objectives. For example, it can be used to . . . .

- . . . . determine the relative priority for individual subject areas within given maintenance occupations (e.g., in the training of mechanical repairmen, subjects on mechanical components have a higher Measure of Effectiveness than that of complex mechanisms and therefore should have a higher priority in the assignment of training time and effort).

. . . . evaluate the relative importance of major subject areas (i.e., mechanics, hydraulics, pneumatics, etc.) to each maintenance occupation.

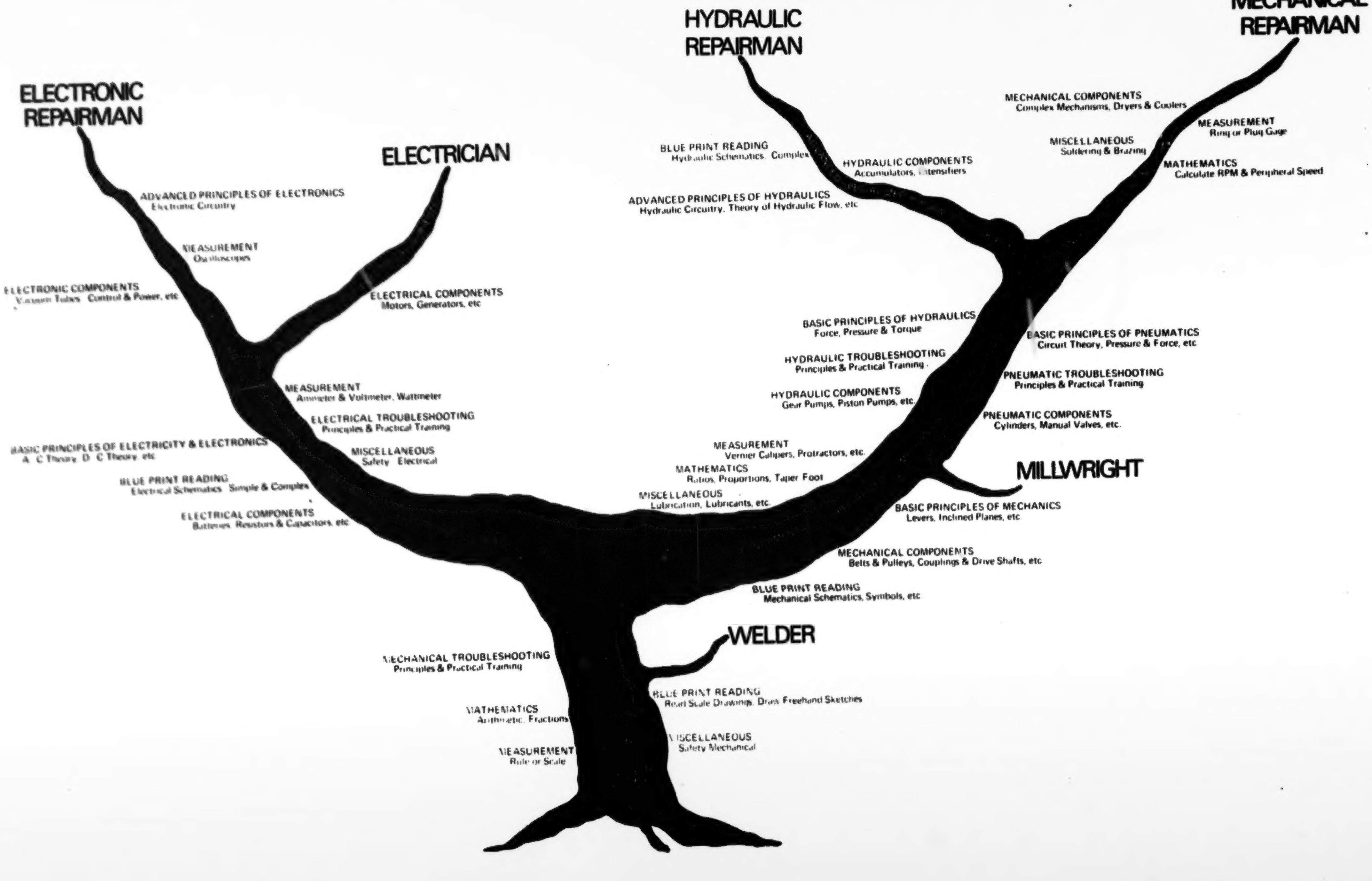
. . . . indicate which subject areas have a sufficient degree of commonality for all maintenance occupations to become basic training courses that should be given to all maintenance workers.

Using this Measure of Effectiveness as a basis for evaluating the relative importance of these subject areas to all maintenance occupations and for assessing their relative priority within each occupation, it was possible to develop the outline for a basic structure for maintenance training. This is shown as a "Machinery Maintenance Training Tree" in Exhibit IV. The Training Tree provides a graphical representation of the overall training requirements in all the machinery maintenance occupations. It not only presents a very useful perspective of the "flow" of trainees through the various subject areas required for training an accomplished maintenance worker, but also delineates the approximate points of "branching" where these trainees move into various occupational specialties in the maintenance field and must receive appropriate training in these areas of specialization.

In developing the Machinery Maintenance Training Tree, subject areas were selected on the basis of the Measure of Effectiveness ranking described previously. In most instances, the subjects included in this basic outline had a Measure of Effectiveness of 60% or greater -- i.e., at least 60% of the respondents indicated that these are subject areas which an accomplished maintenance worker in a particular classification should know to adequately maintain the machinery and production equipment in that particular plant.

EXHIBIT IV

MACHINERY MAINTENANCE TRAINING "TREE"


MECHANICAL REPAIRMAN
HYDRAULIC REPAIRMAN
ELECTRONIC REPAIRMAN
ELECTRICIAN
MILLWRIGHT
WELDER
MECHANICAL COMPONENTS Complex Mechanisms, Dryers & Coolers
MEASUREMENT Ring or Plug Gage
MISCELLANEOUS Soldering & Brazing
MATHEMATICS Calculate RPM & Peripheral Speed
BLUE PRINT READING Hydraulic Schematics, Complex
HYDRAULIC COMPONENTS Accumulators, Intensifiers
ADVANCED PRINCIPLES OF HYDRAULICS Hydraulic Circuitry, Theory of Hydraulic Flow, etc
ADVANCED PRINCIPLES OF ELECTRONICS Electronic Circuitry
MEASUREMENT Oscilloscopes
ELECTRONIC COMPONENTS Vacuum Tubes Control & Power, etc
ELECTRICAL COMPONENTS Motors, Generators, etc
BASIC PRINCIPLES OF HYDRAULICS Force, Pressure & Torque
HYDRAULIC TROUBLESHOOTING Principles & Practical Training
HYDRAULIC COMPONENTS Gear Pumps, Piston Pumps, etc
BASIC PRINCIPLES OF PNEUMATICS Circuit Theory, Pressure & Force, etc
PNEUMATIC TROUBLESHOOTING Principles & Practical Training
PNEUMATIC COMPONENTS Cylinders, Manual Valves, etc
MEASUREMENT Ammeter & Voltmeter, Wattmeter
ELECTRICAL TROUBLESHOOTING Principles & Practical Training
MISCELLANEOUS Safety Electrical
BASIC PRINCIPLES OF ELECTRICITY & ELECTRONICS A. C Theory, D. C Theory, etc
BLUE PRINT READING Electrical Schematics Simple & Complex
ELECTRICAL COMPONENTS Batteries, Resistors & Capacitors, etc
MEASUREMENT Vernier Calipers, Protractors, etc
MATHEMATICS Ratios, Proportions, Taper Foot
MISCELLANEOUS Lubrication, Lubricants, etc
BASIC PRINCIPLES OF MECHANICS Levers, Inclined Planes, etc
MECHANICAL COMPONENTS Belts & Pulleys, Couplings & Drive Shafts, etc
BLUE PRINT READING Mechanical Schematics, Symbols, etc
MECHANICAL TROUBLESHOOTING Principles & Practical Training
MATHEMATICS Arithmetic, Fractions
MEASUREMENT Rule or Scale
BLUE PRINT READING Read Scale Drawings, Draw Freehand Sketches
MISCELLANEOUS Safety Mechanical

Any subject area not attaining a Measure of Effectiveness of 60% or greater was excluded from the Training Tree. Although this 60% level is admittedly an arbitrary cutoff point, it does provide a realistic, objective method by which training requirements in the maintenance field could be structured and evaluated.

However, it should be emphasized that the basic maintenance training structure depicted in Exhibit IV is only intended to provide guidelines in developing individual maintenance training programs. It is quite possible that some of the subject material excluded from this training tree because it does not meet the screening criteria would be included in a specific maintenance training program if the objectives of the program warranted its inclusion.

This method of evaluation used in developing the Machinery Maintenance Training Tree led to the establishment of three categories for these training subjects and the subsequent assignment of each subject to one of these classifications based on the criteria described below:

1. Basic Training Subjects - those which are required by all maintenance workers as indicated by a Measure of Effectiveness of 60% or more for all machinery maintenance occupations.

2. Fundamental Specialized Subjects - those which attained a Measure of Effectiveness of 60% or greater in the mechanically-oriented maintenance occupations (i.e., mechanical repairman, millwright and hydraulic repairman) or an 80% or greater Measure of Effectiveness in the electrically-oriented maintenance occupations (i.e., electrician and electronic repairman).

3. Advanced Specialized Subjects - subjects which are specifically associated with each maintenance occupation and which had a Measure of Effectiveness in excess of 60% within each of these individual occupations.

These classifications are critical to an understanding of the training and skill requirements of machinery maintenance workers and the ability to use the results of this research study to develop effective maintenance training programs. Therefore, each of these classifications is discussed separately below.

III. BASIC MAINTENANCE TRAINING

The basic maintenance training subjects are primarily intended to provide the trainee with a fundamental knowledge that will permit him to assimilate the more advanced training that will be required to become an accomplished maintenance worker in his specific occupational area. A complete listing of these subjects and their Measure of Effectiveness is shown in the chart in Exhibit V. In analyzing the subject areas listed in this chart, it is evident that they represent two different types of subjects. The first encompasses subjects --- simple arithmetic and fractions --- which should be an integral part of the education received by these trainees in the primary and secondary school systems. These would probably not be included in most maintenance training programs unless the programs were concerned with training disadvantaged and unskilled individuals who had not received an adequate basic education.

The second group of basic training subjects provides fundamental technical skills and knowledge that will be necessary to the trainee not only in more advanced maintenance training subjects but also in on-the-job maintenance activities. It includes the capacity to read scale drawings, make freehand sketches, use a scale or ruler, a knowledge of the principles of "trouble-shooting", some practical training in this same subject and a fundamental knowledge of safety practices and procedures. These basic maintenance training subjects are of particular interest in this investigation for two reasons:

Exhibit V

BASIC MAINTENANCE TRAINING

BASIC MAINTENANCE SUBJECTS REQUIRED	Welder	Millwright	Electronic Repairman	Electrician	Hydraulic Repairman	Mechanical Repairman
Blue Print Reading						
Read Scale Drawings	83%	92%	62%	68%	73%	89%
Draw Freehand Sketches	60	74	64	68	71	80
Mathematics						
Arithmetic	91	95	94	94	92	98
Fractions	86	91	87	88	88	93
Measurement						
Rule or Scale	89	96	82	84	90	98
Mechanics						
Troubleshooting:						
Principles	20	59	64	67	79	93
Practical Training	20	58	56	63	72	93
Miscellaneous						
Safety-Mechanical	80	91	59	69	78	97

BASIC MAINTENANCE SUBJECTS NOT REQUIRED	Millwright	Electronic Repairman	Electrician	Hydraulic Repairman	Mechanical Repairman
Blue Print Reading					
Make Scale Drawings	11%	8%	5%	7%	13%
Lettering	6	7	8	7	8
Mathematics					
Metric System	36	27	17	29	44
Algebraic Symbols	21	48	36	27	26
Areas of Geometric Figures	41	19	15	28	37
Angles (Sine, Cosine, etc.)	31	26	18	13	28
Logarithms	3	19	7	4	6
Degrees, Arcs & Sectors of Circles	34	13	10	13	33
Miscellaneous					
Welding-Arc	46	7	16	8	43
Welding-Gas	41	4	9	8	40
Welding-Electronic (Spot, Projection)	19	25	19	7	23
Report Writing	35	50	41	44	42
Slide Rule	10	31	15	13	11

NOTE! Percentages shown are the Measure of Effectiveness for each subject.

Source: Midwest Institute for Research & Training

1. They appear to be quite suitable for vocational training programs in institutions since they require only a minimum amount of training materials and equipment.

2. These basic subjects are applicable not only to machinery maintenance training, but are also common to a multitude of other maintenance and repair occupations ranging from automobile mechanic to business machine repairman and appliance serviceman. (See Appendix C for a more complete listing of the occupational areas in which training in these same basic subjects are required.) It is estimated that more than 5 million individuals are currently employed in business and industry in occupations to which this basic training would apply.

The other aspect of this assessment of the basic training needs of the machinery maintenance field that is of particular importance are those subject areas which do not appear to be of sufficient importance to maintenance workers to be included in training programs. The significance of this information became evident when the subject content of some existing industrial maintenance training courses was analyzed. (See Chapter IV of this report.) For example, a number of existing maintenance training courses provide for courses in engineering drawing and drafting; whereas, the Measure of Effectiveness of this same subject ranged from 5-13%. On the basis of this evaluation, it appears that the capability to make scale drawings is not required of machinery maintenance workers (only an ability to make freehand sketches) and the time spent in providing this training should be expended in other, more useful, subject areas.

IV. FUNDAMENTAL SPECIALIZED TRAINING

As was indicated by the Machinery Maintenance Training Tree, the first basic "branching" of maintenance training into specialized occupations occurs between mechanically and electrically-oriented subject areas.

This demarcation of mechanical and electrical maintenance training follows a fundamental characteristic of maintenance functions within an industrial maintenance department and is often firmly established by union contract provisions. Also, for the trainee, the choice of which "branch" to pursue would usually be made at this point in a training program and is normally the result of his natural interests and capabilities.

A sharp distinction was evident in the results of the survey concerning the specific training needs in these two fundamental aspects of maintenance training, with only a small degree of overlap in such areas as the basic principles of troubleshooting and safety practices. For this reason, it is necessary to discuss each separately.

A. Mechanical Training

Initially, it was expected that mechanical training would encompass the mechanical repairman, millwright, hydraulic repairman and welder. An analysis of the Measure of Effectiveness for this last occupational area (welder) indicated that the maintenance welder is a highly specialized occupation. Beyond the basic maintenance subjects discussed previously, the welder's training and skill needs are solely oriented about the manipulative skills of welding and a detailed knowledge of welding, soldering and brazing procedures. Additional field interviews confirmed this conclusion and, as a result, the welder was not included in the assessment of training and skill requirements at this level.

A comprehensive listing of the specific subject areas included in this mechanical training is shown in Exhibit VI. As indicated in this chart, they encompass a wide range of training subjects --- the ability to "read" mechanical and hydraulic symbols and schematic drawing, a mathematical knowledge of ratios and proportions, the capability to use a number of measuring devices, simple principles of mechanics embodied in cams, gears, pulleys and similar mechanical devices,

Exhibit VI

FUNDAMENTAL SPECIALIZED MECHANICAL TRAINING

REQUIRED SUBJECTS	Hydraulic Repairman	Mechanical Repairman	Millwright
Blue Print Reading			
Mechanical Schematics	*69%	97%	82%
Symbols	48	80	75
Hydraulic Schematics - Simple	91	68	37
Mathematics			
Ratios, Proportions & Taper/Foot	50	78	69
Measurement			
Vernier Calipers	52	88	71
Protractor	43	79	69
Micrometer	56	93	69
Screw Threads	47	90	69
Dial Indicator	58	92	67
Mechanics			
Basic Principles:			
Levers	63	92	88
Inclined Planes	39	73	78
Pulleys & Gears	56	96	87
Cams & Other Mechanisms	56	87	64
Mechanical Components			
Belts & Pulleys	47	95	80
Couplings & Drive Shafts	48	94	81
Ball & Roller Bearings	50	95	81
Sleeve Bearings	40	95	80
Wear Plates & Ways	23	89	70
Spur Gears	33	92	68
Bevel, Worm, Gears, etc.	30	90	66
Clutches & Brakes	43	95	74
Cams & Followers	37	87	58
Conveyors	27	88	81
Hydraulics			
Basic Principles:			
Force, Pressure & Torque	93	63	46
Troubleshooting:			
Principles	92	70	31
Practical Training	93	67	33

*Measure of Effectiveness

Source: Midwest Institute for Research & Training

FUNDAMENTAL SPECIALIZED MECHANICAL TRAINING

REQUIRED SUBJECTS	Hydraulic Repairman	Mechanical Repairman	Millwright
Hydraulic Components			
Gear Pumps	* 87%	78%	38%
Piston & Vane Pumps	81	75	35
Tubing & Fittings	92	67	42
Filters	91	66	30
Pressure Gages	91	68	36
Manually-operated Valves	93	72	41
Solenoid & Pilot-operated Valves	91	60	29
Relief Valves	92	68	34
Cylinders	92	71	35
Packing & Seals	90	80	46
Heat Exchangers	77	58	33
Pneumatics			
Basic Principles:			
Circuit Theory	78	76	40
Pressure & Force	79	77	39
Troubleshooting:			
Principles	71	78	34
Practical Training	69	78	31
Pneumatic Components			
Cylinders	70	79	34
Manual Valves	72	79	36
Solenoid & Pilot-operated Valves	72	71	29
Compressors	57	85	42
Lubricators & Filters	74	85	42
Regulators & Pressure Gages	73	82	38
Mufflers	59	71	31
Motors & Rotary Actuators	61	66	29
Miscellaneous			
Lubrication	71	92	76
Lubricants	61	93	70
Pipefitting	71	77	67

* Measure of Effectiveness

Source: Midwest Institute for Research & Training

and a knowledge of specific types of mechanical components that are normally found in production machinery and equipment.

This chart also points out a dichotomy that emerged from an analysis of the survey results between the mechanical repairman/millwright and the hydraulic repairman. A comparison of the Measure of Effectiveness in many of these mechanical training subjects indicates that providing common subject material to these three occupations would result in overtraining hydraulic repairmen in mechanical maintenance subjects and in overtraining mechanical repairmen and millwrights in hydraulic maintenance subjects. However, it was decided to combine these somewhat different training requirements into a single set of fundamental mechanical training requirements for two primary reasons:

1. The number of hydraulic repairmen in industry's maintenance workforce is relatively insignificant in comparison with the number of mechanical repairmen and millwrights in industry and in most instances the overtraining of hydraulic repairmen in mechanical maintenance subjects would be justified on economic considerations.

2. As discussed in Chapter V of this report, the application of sophisticated hydraulic servo concepts to production machinery and equipment is growing rapidly and it is likely that the overtraining of mechanical repairmen and millwrights in hydraulic maintenance will prove to be justified in time.

In the event that the need arises to separate this agglomerate mechanical training and develop specialized hydraulic maintenance training programs, the information contained in Exhibit VI can be utilized to structure such a program.

B. Electrical Training

Electrical Training encompasses both the electrician and the electronic repairman. As shown in Exhibit VII, considerable commonality exists in the training and skill requirements of these two maintenance occupations at this level. To a large extent, this commonality can be attributed to the recent emergence of electronic maintenance as a specialized occupation and the natural tendency to upgrade electricians into this new maintenance function. In time, it is expected that a more direct training "path", similar to that of the hydraulic repairman, will become evident.

One other major aspect of this area of fundamental specialized training became evident during this investigation. An examination of the individual subjects included in this facet of maintenance training reveal that they encompass a number of degrees of training complexity. At one end of the scale are subjects such as blueprint symbols and reading hydraulic, pneumatic and electrical schematic drawings which can best be taught in the classroom and require only a minimum amount of special training equipment. Therefore, they are more suitable for classroom vocational training programs. At the other end of this spectrum are training subjects dealing with machinery components that involve complex training equipment and require some on-the-job exposure as an integral part of the training. These subjects can be better undertaken by industry alone or jointly with educational institutions.

It appears that at some point in this area of fundamental specialized training an "interface" exists between class-oriented training activities and on-the-job oriented training activities. The former are most compatible with vocational training programs in schools; whereas, the latter are probably most compatible with industry training programs. A number of industrial training directors indicated that a major "gap" now exists in the classroom-oriented facets of this fundamental specialized training. They also felt that this interface area was one in which vocational and trade school are presently least effective in their training efforts and yet would be most valuable in

Exhibit VII

FUNDAMENTAL SPECIALIZED ELECTRICAL TRAINING

REQUIRED SUBJECTS	Electronic Repairman	Electrician
Blue Print Reading		
Electrical Schematics - Simple	*82 %	93%
Electrical Schematics - Complex	79	76
Measurement		
Ammeter & Voltmeter	94	99
Wattmeter	88	94
Electrical + Electronics		
Basic Principles:		
A-C Theory	94	99
D-C Theory	93	94
Circuitry (Series, Parallel)	93	99
Wiring Fundamentals	91	97
Color Coding	91	96
Troubleshooting		
Principles	95	94
Practical Training	78	75
Components		
Batteries	86	93
Resistors & Capacitors	95	83
Limit Switches	83	98
Relays	93	97
Transformers	87	96
Miscellaneous		
Safety-Electrical	86	95

*Measure of Effectiveness.

Source: Midwest Institute for Research & Training

enabling individuals to find employment in industry's maintenance workforce. In total, it appears that this fundamental specialized training is one of the most critical aspects of the maintenance training and the area in which initial efforts to resolve these problems should be concentrated.

V. ADVANCED SPECIALIZED TRAINING

The final "branchings" of the Machinery Maintenance Training Tree evolve into certain courses aimed specifically at individual maintenance occupations -- mechanical repairman, millwright, hydraulic repairman, electrician or electronic repairman. The subject areas included in this advanced specialized training for each maintenance occupation are shown in Exhibit VIII, along with their Measure of Effectiveness as determined from the survey results. In most cases, this advanced specialized training can most effectively be provided by industry in its maintenance training programs because of the requirements for costly specialized equipment used in the training. Furthermore, a considerable portion of the time devoted to this advanced specialized training has to be on-the-job and the role of vocational schools in this aspect of maintenance training is likely to be limited to special cases such as the training of aircraft maintenance mechanics where the training equipment can be obtained at little or no cost from the Federal Government and where extensive training curriculums have already been established.

VI. THE COMMONALITY OF MACHINERY MAINTENANCE TRAINING REQUIREMENTS

The commonality of training requirements for different occupations within the maintenance field is a basic conclusion of this report. This study maintains that the different specialized occupations of machinery maintenance have common skill and training requirements until the most advanced levels of instruction are reached. The "Machinery Maintenance Tree" indicates that all prospective machinery maintenance workers (at least those entering the six occupations studied) should be provided with the same basic training.

Exhibit VIII

ADVANCED SPECIALIZED TRAINING

MECHANICAL

	Mechanical Repairman	Millwright	Hydraulic Repairman
ADVANCED SPECIALIZED MECHANICAL REPAIRMAN SUBJECTS			
Mathematics			
Calculate RPM; Peripheral Speed	76%	52%	39%
Measurement			
Ring or Plug Gage	77	47	42
Components			
Complex Mechanisms	72	38	32
Dryers & Coolers (Pneumatics)	69	9	53
Miscellaneous			
Soldering & Brazing	63	46	38
ADVANCED SPECIALIZED HYDRAULIC REPAIRMAN SUBJECTS			
Hydraulics			
Basic Principles:			
Hydraulic Circuitry	54	26	96
Theory of Hydraulic Flow	44	19	89
Hydraulic Fluids	40	23	89
Components			
Accumulators	54	26	88
Intensifiers	41	21	81
Blue Print Reading			
Hydraulic Schematics-Complex	20	9	81

ELECTRICAL

	Electrician	Electronic Repairman
ADVANCED SPECIALIZED ELECTRICIAN SUBJECTS		
Components		
Motors	99%	70%
Generators	94	67
Starters	96	69
Solenoid-operated Valves	62	38
ADVANCED SPECIALIZED ELECTRONIC REPAIRMAN SUBJECTS		
Measurement		
Oscilloscopes	41	92
Electrical + Electronics		
Basic Principles: Electronic Circuitry	74	95
Components		
Vacuum Tubes - Control	53	94
Vacuum Tubes - Power	56	95
Transistors	51	95
Oscillators	37	90
Pentiometers	68	93
Syncros + Servomechanism	50	86
Electric Eyes	77	89
Silicon-Controlled Rectifiers	60	91

Source: Midwest Institute for Research & Training

Furthermore, at the fundamental specialized level of training, each occupation receives one of only two programs of instruction.

The commonality of training requirements among different machinery maintenance occupations is not only basic to our report but is also vital to the feasibility of providing meaningful maintenance training in institutions of education before the workers enter the labor market and in classrooms of industrial training programs. The commonality of training requirements makes the training program outlined in this chapter a feasible and preferable alternative to "machine-by-machine" training.

This part of our study was conducted to provide a basic explanation for the commonality of training requirements among different machinery maintenance occupations and thus give support to this report's findings.

The assumption was made that production machinery consisting of similar systems (mechanical, electrical, etc.) and of similar components (bearings, brakes, etc.) would have similar maintenance problems whose solutions would require maintenance workers with similar skills and training. For example, the maintenance requirements for a 1/2 h. p. electric motor installed on a mixing machine in a food processing plant and an identical 1/2 h. p. motor that operates a conveyor in a metal stamping plant should not differ significantly. A maintenance electrician in the food processing plant should require the same knowledge and skills to service and repair the motor as a maintenance electrician in the metal stamping plant. Thus a study was made of the various types of industrial machinery and equipment used in different industries (See Appendix D).

The results of this machinery inventory are shown in Exhibit IX, which shows the relative frequency of occurrence for these major components and characteristics. As this chart indicates, mechanical, electrical and lubrication systems were encountered in more than 80% of the production machinery and equipment inventoried; hydraulic systems occurred in 40-60%

Exhibit IX

SUMMARY OF SURVEY OF CHARACTERISTICS AND COMPONENTS OF PRODUCTION MACHINERY

MAJOR MACHINERY COMPONENTS AND CHARACTERISTICS	FREQUENCY OF OCCURANCE (% OF TOTAL)				
	>80	60-80	40-60	20-40	<20
Mechanical Systems	X				
Bearings, Ball & Roller		X			
Bearings, Journal		X			
Shafts & Couplings	X				
Belt & Pulley Drives		X			
Cams & Followers			X		
Brakes & Clutches			X		
Gears & Gear Trains		X			
Hydraulic Systems			X		
Low Pressure (<100 PSI)					X
High Pressure (>100 PSI)					X
Cylinders				X	
Pumps				X	
Motors & Actuators					X
Packing & Seals			X		
Valves, Pressure & Flow Control			X		
Valves, Directional & Switching			X		
Gages			X		
Pneumatic Systems				X	
Cylinders					X
Motors and Actuators					X
Valves, Pressure & Flow Control				X	
Valves, Directional and Switching				X	
Gages				X	

Exhibit IX

SUMMARY OF SURVEY OF CHARACTERISTICS AND COMPONENTS OF PRODUCTION MACHINERY (CONT.)

MAJOR MACHINERY COMPONENTS AND CHARACTERISTICS	FREQUENCY OF OCCURANCE (% OF TOTAL)				
	> 80	60-80	40-60	20-40	< 20
Electrical Systems	X				
DC Systems					X
AC Systems	X				
Pushbutton & Selector Switches	X				
Motors & Starters (AC)	X				
Transformers & Rectifiers				X	
Relays				X	
Limit Switches			X		
Solenoids			X		
Indicating Lights				X	
Electronic Systems					X
Lubrication Systems	X				
Lubricant - Oil	X				
Lubricant - Grease		X			
Manual Systems	X				
Automatic Systems				X	

Source: Midwest Institute for Research and Training of this equipment; pneumatic systems in only 20-40% and electronic systems in less than 20% of the equipment analyzed. The chart also lists the frequency of occurrence for some of the major components in each of these system categories. For example, in the mechanical systems, shafts and coupling appeared in more than 80% of the equipment inventoried; ball, roller and journal bearings, belt and pulley drives, and gears and gear trains appeared in 60-80% of this machinery; cams and followers and brakes and clutches in 40-60% of the equipment.

On the basis of this analysis, it appears that production machinery varies substantially in size, operating characteristics, function, appearance and other external characteristics, but, internally, this machinery is sufficiently composed of similar systems and individual components to permit the course of action discussed previously.

VII. THE ROLE OF THE MULTI-SKILL MAINTENANCE SPECIALIST

The one subject in the entire field of maintenance manpower and training requirements that evokes the most controversy concerns whether industry needs multi-skill maintenance specialists. This individual, who would be trained in mechanical, hydraulic, electric and perhaps even electronic maintenance, ideally would be able to resolve almost any machinery maintenance problem that might arise. The apparent need for this multi-skill capability has arisen out of the growing sophistication and complexity of modern production equipment. It is not unusual for a situation to arise in which a "breakdown" of production machinery occurs and it is impossible to determine initially if the source of the problem is in the mechanical or the electrical portions of the machinery. As a result, it is sometimes necessary to have mechanical repairmen and electricians working on the problem simultaneously until the source of the trouble can be identified. Once the specific cause of the trouble has been identified, the task of returning the equipment to proper operating condition is normally assigned to the maintenance worker in whose field the problem falls. Hopefully, a single

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multi-skilled maintenance worker would be able to identify the source of the problem and undertake the necessary maintenance and repairs.

Since the role of this multi-skill maintenance worker in industry has a direct impact on the manpower and training requirements of the machinery maintenance field, a special effort was made during this investigation to provide some answers to this question. On the basis of the discussions and in-depth interviews with plant engineers, maintenance supervisors and training directors, it appears that the multi-skill maintenance specialist will not become commonplace in industry's maintenance workforce for two reasons:

1. The critical need for this multi-skill capability is not in the actual maintenance and repair of production machinery but in the diagnosis and identification of the source of equipment malfunctions and breakdowns.

2. Union contract provisions in most large manufacturing plants essentially prohibit the use of the multi-skill maintenance specialist (in some plants the mechanical repairmen and millwrights are represented by one union and the maintenance electricians by another) and it is unlikely that these restrictions will be altered in the foreseeable future.

It appears that the multi-skill maintenance specialist will be replaced by a new maintenance occupation --- the maintenance technician --- who will emerge during this period. The function of this maintenance technician will be primarily to identify the source of machinery maintenance problems, but not to undertake the actual maintenance and repair of this equipment. It appears that this maintenance technician will need a higher level of education and technical training than is presently required of maintenance workers --- probably a combination of post-secondary school education and specialized technical maintenance training. At the present time, little or no effort is being devoted to this maintenance technician occupation and yet it is expected to be one of the increasingly more critical industrial occupations that will evolve during the next 5-10 years.

VIII. CLASSROOM VS. ON-THE-JOB MACHINERY MAINTENANCE TRAINING

There are a number of subject areas (e.g., freehand sketching, blueprint reading, mathematical ratios and proportions, etc.) which can best be taught under classroom conditions. However, as the subject areas covered in maintenance training programs increase both in complexity and in degree of specialization, it becomes difficult to determine the relative role which classroom instruction and on-the-job training should play in providing this training.

The attitudes and opinions expressed by plant engineers and maintenance supervisors indicate, ". . . . the less classroom training the better we like it." This position is both practical and understandable since there is a notable (and almost tragic) lack of adequate training courses, textbooks and materials in this field of machinery maintenance. As a result, with the exception of the few basic subjects noted previously, on-the-job training is the only effective vehicle available to provide this training. Probably 80-90% of the total amount of maintenance training provided in this country takes place under on-the-job conditions --- often without any formal training program or direction. However, it is also readily apparent that much of this on-the-job training is inadequate, particularly in regard to providing a knowledge and understanding of basic concepts.

During these investigations, a number of industrial training programs were contacted and visited in which formal classroom instruction accounted for a surprisingly high proportion of their maintenance training. The primary difference between these training programs and the on-the-job training most commonly found in industry is that these companies had invested substantial sums of money in development of adequate training materials for their training programs. Some companies, such as Ford and DuPont, have multi-million dollar investments in the maintenance training materials they have developed and are using. The airlines in particular (e.g., United, American and TWA) have full time staffs working on the development of these training materials and utilize sophisticated audio and visual training concepts, including some current experimentation with video-tape as a training medium.

It appears that the primary obstacle to the expansion and improvement of adequate maintenance training programs in the schools and in industry is this lack of adequate training materials. Certain aspects of maintenance training in basic and fundamental specialization-subjects can and perhaps should be provided through vocational and adult education programs, but the lack of these training materials will greatly limit the extent to which maintenance training can be introduced at the institutional level. The most immediate concern in this entire problem of maintenance training should be directed at devising methods by which more and better training materials can be made available. Some specific suggestions concerning how this might be accomplished are contained in the final chapter of this report.

* * * * * * *

This chapter has been concerned with a number of important aspects of this entire question of the training and skill requirements of industrial machinery maintenance workers. The results of these discussions can be summarized by several key points:

1. A high degree of commonality exists in machinery maintenance requirements throughout all of industry and it is reasonable to expect that similar knowledge and skills are required of maintenance workers throughout industry.

2. Through a series of detailed personal interviews and a questionnaire survey of plant engineers and maintenance supervisors, a Machinery Maintenance Training Tree was developed which presents a logical progression of training and the subject areas which should be taught at three levels:

   - Basic Maintenance Training
   - Fundamental Specialized Training
   - Advanced Specialized Training

3. Subject areas in Basic Maintenance Training and some subjects in Fundamental Specialized Training are particularly suitable for vocational and adult training programs; the remainder of the subject areas in Fundamental Specialized Training and all of the Advanced Specialized Training appear to be better provided by industry, either alone or jointly with educational institutions.

4. The basic training subjects appear not to be limited merely to machinery maintenance training but apply to other maintenance occupations (e.g., appliance repairman, automotive mechanic, etc.) which encompass approximately 5 million workers in business and industry.

5. A major gap presently exists between the basic maintenance training provided by schools and other institutions and the "minimum" training requirements expected by industry of new maintenance trainees, with most of this gap being confined to basic and some fundamental specialization subject areas.

6. Production machinery varies substantially in size, function, etc.; however, internally this machinery is composed of similar systems and components. Thus, machinery in various industries has similar maintenance problems and requirements. This explains the commonality of maintenance training requirements for various occupations.

7. It appears that the multi-skill machinery maintenance specialist will have a very limited role in industry's workforce but that a new occupation --- maintenance technician --- will emerge during the next 10 years to provide the specialized diagnostic and troubleshooting capabilities that are becoming an increasingly important part of industry's machinery maintenance procedures.

8. Probably the most critical problem in the entire field of machinery maintenance training is the lack of adequate training courses, textbooks and other training materials for this field.

CHAPTER FOUR

EXISTING MAINTENANCE TRAINING PROGRAMS

EXISTING MAINTENANCE TRAINING PROGRAMS

How well do existing maintenance training programs meet the maintenance training and skill requirements defined in the previous chapter? Of course, it is necessary to answer this question to determine whether new programs are necessary, and to identify the type of new course material needed. Thus an evaluation of existing programs was undertaken. However, it proved to be extremely difficult to identify the amount, type, and quality of the training given machinery maintenance personnel. Adequate statistics relating to industrial and institutional maintenance training programs are not available. Furthermore, industrial firms have made little attempt to conduct in-depth job analysis to determine the relationship between present maintenance training and job content.

Although machinery maintenance plays an extremely vital role in our industrial economy, information collected during this study in combination with the results of other worker training surveys taken during the past several years, indicate that very little formal machinery maintenance training is given workers in industry --- most maintenance workers receive whatever training they get informally, while on the job. Yet, extensive discussions with industrial training directors, plant engineers, and maintenance supervisors indicate that more and better training is required to meet the changing maintenance needs of industry. Because of the lack of adequate formal training programs, it is evident that most maintenance workers are not provided with the fundamental skills and knowledge required to give them the flexibility to handle unusual or new maintenance situations and to cope with new machinery technology as it is introduced.

I. THE SOURCE OF TRAINING IN THE MAINTENANCE FIELD

Information obtained during this study suggests that nearly all training in the machinery maintenance occupations is received in connection with industrial employment. This observation is confirmed by a U.S. Department of Labor survey (see Exhibit X) which shows that the majority of mechanics and repairmen received their most significant training through industry-

Exhibit X

METHOD BY WHICH MECHANICS AND REPAIRMEN LEARNED THEIR TRADE [a)]

Results of 1963 Survey of Worker Training

Method of Learning	Percent of Mechanics & Repairmen: All Ways of Learning	Percent of Mechanics & Repairmen: Most Helpful Way of Learning
Formal Training	38.7	10.6
School		5.6
Apprenticeship		2.8
Armed Forces		2.2
On-the-Job Learning	65.7	37.8
On-job instruction		29.4
Company training course		6.0
Worked way up		2.4
Casual Methods	50.7	27.0
From friend or relative		3.8
Picked it up		20.8
Other		2.4
Unknown	0.3	21.1
No Training Needed	3.6	3.6
TOTAL		100.0

a) The survey covered 983,000 persons working as "other mechanics and repairmen" referred to here as mechanics and repairmen. This classification specifically excludes airplane, auto, and radio and television mechanics but would appear to include appliance and office machine as well as industrial machine repairmen. All were civilian workers 22 to 64 years old who completed less than 3 years of college.

Source: U.S. Department of Labor, Formal Occupational Training of Adult Workers -- Its Extent, Nature and Use, Manpower/Automation Research Monograph No. 2, Table 11, page 44, U.S. Department of Labor, Office Manpower, Automation and Training, December 1964 connected on-the-job training, formal apprenticeship training programs and casual methods of instruction; whereas only 5.6% of the persons in this classification received their most significant training in schools and other institutional programs. This reliance on industry for training is understandable since considerable emphasis is normally placed on practical experience rather than on classroom instruction. Thus, maintenance trainees traditionally are expected to spend most of their time obtaining practical experience while on-the-job in industry. Their classroom training activities, if any, are normally confined to such basic maintenance subjects as basic mathematics, engineering drafting, blueprint reading and simple "shop" courses.

This U.S. Department of Labor survey also provides an important insight into the role which various types of training institutions play in providing formal maintenance training. As indicated in Exhibits X and XI, high schools and junior colleges are a relatively insignificant source of formal maintenance training. However, the overall contribution of high schools to maintenance training is undoubtedly understated in these two surveys since the primary function of secondary schools is that of providing students with the basic educational skills and knowledge prerequisite to machinery maintenance as well as many other occupational fields. At the present time, few schools at the secondary level offer machinery maintenance as a specific training program. Even with the increasing emphasis on vocational-technical schools designed to provide more specific occupational skills at the secondary level for employment after graduation, it is unlikely that secondary schools will provide many trained machinery maintenance workers for industry in the foreseeable future.

Because machinery maintenance workers are largely skilled tradesmen rather than technicians, it is not surprising that very few formal machinery maintenance programs are offered at the post-high school level. The junior

Exhibit XI

ORGANIZATION IN WHICH FORMAL MAINTENANCE TRAINING WAS RECEIVED [a]

Results of 1963 Survey of Worker Training

Type of Institution in Which Formal Training Was Received	Percent of Programs [c]
Armed Forces	21.8
Special School	18.7
Correspondence School	15.1
Apprenticeship	13.7
Technical Institute	13.1
Company School [b]	12.8
High School	3.8
Junior College	0.7
Other	0.2
TOTAL	100.0

[a] The survey covered 983,000 persons working as "other mechanics and repairmen" referred to here as mechanics and repairmen. This classification specifically excluded airplane, auto, and radio and television mechanics but would appear to include appliance and office machine as well as industrial machine repairmen. All were civilian workers 22 to 64 years old who completed less than 3 years of college.

[b] Program at a company training school attended full-time for six weeks or more.

[c] Percent of all mechanics and repairmen training programs.

Source: U.S. Department of Labor, Formal Occupational Training of Adult Workers -- Its Extent, Nature and Use, Manpower/Automation Research Monograph No. 2, Table 4, p. 37, U.S. Department of Labor, Office of Manpower, Automation and Training, December, 1964.

colleges and trade schools are, however, becoming a more important source of related classroom instruction supported by industry for individuals on formal industrial training programs. In addition, graduates of the two-year engineering technology programs (electrical, mechanical, electro-mechanical, electronic, and tool technology) provided by some junior colleges do occasionally enter jobs involving maintenance responsibilities. As discussed in the preceding section of the report, the expected emergence of the maintenance technician as an important element in industry's maintenance operations will probably increase the contribution which post-secondary schools make to this field of training.

One other significant and somewhat surprising source of formal maintenance training is the Armed Forces. Although Exhibit X indicates that only 2.2% of maintenance mechanics and repairmen received their most significant training (formal and informal) in the Armed Forces, Exhibit XI showed that 22% of the formal maintenance training programs reported were taken in the Armed Forces. Assuming a continuation in the present military draft system, the Armed Forces should continue to be an important source of formal training in the maintenance field.

II. INDUSTRY'S MAINTENANCE TRAINING ACTIVITIES

As has been indicated, industry is the primary source of maintenance training and most of this training is provided informally. A recent survey of the metalworking industry conducted by the Stanford Research Institute shows that only 23% of the plants in this field have formal training or apprenticeship programs in maintenance-related occupations (See Exhibit XII). This survey indicates that larger plants are more likely to have a formal training program than are smaller plants --- as many as 41% of large plants have a training program compared to only 18% of the small plants. The S.R.I. survey also indicates that 87% of metalworking plants reporting a formal training program have an apprenticeship program; only 22% have a formal non-apprenticeship training program and 9% have both. As can be seen in Exhibit XIII, the majority (69%) of the apprenticeship programs are registered with a state apprenticeship agency or by the Bureau of Apprenticeship and Training. However, it should be noted that a number of the most comprehensive machinery maintenance training programs encountered during this investigation were not registered.

A recent report on the status of apprenticeship programs released by the U.S. Department of Labor indicates that formal apprenticeship programs seem to be increasing as a source of training for machinery maintenance workers. As can be seen in Exhibit XIV, the number of registered apprentices in the maintenance mechanical repairmen and millwright occupations increased by 24% during 1965 --- compared to a 22% increase in all metalworking trades apprentices and an 8% increase for all apprentices in training.

Exhibit XII

PERCENT OF PLANTS WITH MAINTENANCE TRAINING AND APPRENTICESHIP PROGRAMS

Based on a Survey of Training in
the Metalworking Industry

Type of Training Program	Percent of Plants with Employees in Each Trade a)			
	Maintenance Electrician	Maintenance Mechanic	Millwright	Average
Both training and apprenticeship programs	3%	2%	0%	2%
Training Programs Only	3%	5%	1%	1%
Apprenticeship programs only	17%	16%	21%	18%
Neither training nor apprenticeship programs	75%	76%	76%	76%
No answer	1%	2%	1%	1%
Total	100%	100%	100%	100%

a) Weighted average of the three maintenance-related occupations shown.

Source: Kincaid, Harry V., The Scope of Industrial Training in Selected Skilled and Technical Occupations, p. 31, Stanford Research Institute, October, 1966

Exhibit XIII

MAINTENANCE APPRENTICESHIP PROGRAMS
REGISTERED OR UNREGISTERED

Based on a Survey of Training in the Metalworking Industry

	Percent of Plants with Apprentice Program			
	Maintenance Electrician	Maintenance Mechanic	Millwright	Average a)
Program registered	68%	74%	64%	69%
Program not registered	32%	26%	34%	31%
No answer	--	--	1%	--
Total	100%	100%	100%	100%
Base (Weighed number of plants with apprentice program in each trade)	392	325	262	--

Detail may not add due to rounding.

a) Weighted average of the three maintenance-related occupations shown.

Source: Kincaid, Harry V., The Scope of Industrial Training In Selected Skilled and Technical Occupations, Table 16, p. 42 Stanford Research Institute, October, 1966

Exhibit XIV

APPRENTICESHIP REGISTRATION IN MAINTENANCE-RELATED TRADES

Trade	Number of Apprentices [a)]		Percent Increase
	12/31/64	12/31/65	
Maintenance Mechanics Repairmen	2,266	2,930	24.3%
Millwright	1,324	1,735	23.7%

a) Active Apprentices Registered with State Apprenticeship Agencies or the Bureau of Apprenticeship and Training

Source: U.S. Department of Labor, Bureau of Apprenticeship and Training, Apprentice Registration Actions --- Miscellaneous Trades, 1965, Bulletin No. 66-140, June 30, 1966

III. APPRENTICESHIP PROGRAMS IN INDUSTRY

The majority of formal maintenance training programs in industry are apprenticeship programs. Furthermore, it appears that nearly all non-apprenticeship programs are based on the apprenticeship style of training, i.e., a formalized program of on-the-job instruction with, in most instances, a program of related classroom instruction. These programs closely follow the same general structure --- one hour of related instructions for every fourteen hours of on-the-job training. This ratio meets the suggested minimum criteria recommended by the Federal Committee on Apprenticeship. All of these programs also meet the Committee's requirements of two or more year (4,000 hours or more) of work experience, Most include related classroom instruction designed to provide the apprentice with knowledge in technical subjects related to his trade. A minimum of 144 hours per year of such instruction is normally considered necessary for such programs.

On-the-job requirements for maintenance apprentices in programs studied ranged from a minimum of 4,000 hours to a maximum of 12,000 hours. Related instruction, whether by correspondence, factory classroom, or institution, ranged from a minimum of approximately 300 hours for a two-year program to 800 hours and more for 4, 5 and 6-year apprenticeship programs. This wide variation in the length of machinery maintenance training programs encountered in these investigations were corroborated by the results of SRI's study (shown in Exhibit XV) of apprenticeship programs in the metalworking field.

A more detailed analysis of these machinery maintenance training programs revealed a number of reasons for this wide variation in the length of these programs. In many instances, particularly in smaller plants, a man designated as a machinery repairman, maintenance electrician, millwright, or other maintenance classification, will serve as an all-around machinery maintenance man and perhaps also as a maintenance machinist. As a result, these training programs are likely to be more comprehensive and therefore require more time to complete. (It is somewhat paradoxical to note that maintenance workers in smaller plants are probably in most need of training in a wide range of maintenance functions and yet these plants are least likely to be able to meet the cost of providing the training.) In other instances, particularly in large unionized plants, both the complexity of the maintenance task and trade jurisdictional considerations dictate that a considerable amount of maintenance specialization be maintained. Also, some maintenance training programs specialize in the particular needs of a specific industry because of unique production equipment involved. In these types of plants, the training programs are "tailored" to the needs of specific maintenance activities, thereby reducing the amount of time that is required to impart this training.

Exhibit XV

LENGTH OF MAINTENANCE APPRENTICESHIP PROGRAMS

Based on a Survey of Training in the Metalworking Industry

	Percent of Plants with Apprentice Program in Each Trade			
Length of Program	Maintenance Electrician	Maintenance Mechanic	Millwright	Average[a)]
Less than 1 year	14%	2%	6%	8%
1 year	1	--	2	1
2 years	12	8	6	9
3 years	2	7	50	16
4 years	67	82	36	64
5 years	3	--	--	1
6 years	--	--	--	--
7 years	--	--	--	--
8 years	--	2	--	--
Total	100%	100%	100%	100%
Base (Weighted number of plants with apprentice program in each trade)	406	326	263	---

Items may not add due to rounding.

a) Weighted average of the three maintenance-related occupations shown.

Source: Kincaid, Harry V., The Scope of Industrial Training in Selected Skilled and Technical Occupations, Table 20, p. 45, Stanford Research Institute, October, 1966.

IV. ON-THE-JOB MAINTENANCE TRAINING ACTIVITIES

The on-the-job portion of machinery maintenance training programs is by far the largest segment of formal industrial programs investigated. As indicated previously, the emphasis on this type of training activity is a result of two factors --- a traditional feeling that on-the-job training is the only way to impart required skills and knowledge, and the notable lack of adequate training materials in the machinery maintenance field. The primary difficulty encountered in this evaluation of the on-the-job portion of these training programs was the unavailability of any in-depth analysis of the maintenance functions to establish best methods by which this training should be imparted. The results of the survey of plant engineers and maintenance supervisors provided a basic frame of reference for determining training requirements, but the survey was unable to establish what combination of on-the-job training and classroom instruction would be most effective in providing the required knowledge and skills. A detailed study now being conducted by Ford Motor Company of various maintenance functions in all of the company's plants should provide a particularly useful tool in analyzing the effectiveness of existing maintenance training programs. Because of the lack of a suitable "yardstick," this investigation was limited to a comparison of one program's on-the-job training activities to those of other programs of a similar nature. However, even this imperfect comparison revealed a number of major inconsistencies in this on-the-job training that suggest that much more research is needed in this area.

Typical on-the-job training schedules for a number of machinery maintenance occupations are shown in Appendix E. These schedules normally involve 8,000 hours of on-the-job training, encompassing a 3-5 year period of training. An analysis of on-the-job training in the programs examined during this investigation suggests that many existing programs are longer than is necessary to provide the on-the-job training that appears to be required. In some cases, the trainee is assigned to very routine, undesirable jobs which provide little or no training. For example, the study uncovered several companies who regularly assigned maintenance electrician trainees to the job of changing lightbulbs on a nearly full-time basis for their first several months of apprenticeship. In many instances, it appears that the amount of on-the-job training was arbitrarily allocated merely to "fill" an 8,000 hour training schedule. Since unnecessarily lengthy training represents waste of valuable resources for both the trainee and the company, it is evident that further effort should be devoted to examining on-the-job training requirements. Based on the limited amount of information generated during this investigation, it appears that a 2-3 year formal program would be suitable for most machinery maintenance training.

V. RELATED CLASSROOM INSTRUCTION

Classroom instruction is an integral part of most formal maintenance training programs as is indicated in Exhibit XVI. In these programs, related instruction represents from 7-10% of the total training time. This segment normally contains a core of subjects common to most maintenance occupations. Although the data presented in Exhibit XVI indicates that both company employees and institutional instructors are used to provide the instruction, the analysis of major corporate apprenticeship programs undertaken during this study found very few companies using company personnel for more than one or two of these related courses. In most cases, the junior colleges or high schools were utilized during the afternoons and evenings for this purpose. Private technical schools and correspondence schools also provided a significant amount of the related instruction in the training programs examined during the course of the study.

Exhibit XVI

FORMAL CLASSROOM INSTRUCTION IN MAINTENANCE APPRENTICESHIP PROGRAMS

Based on a Survey of Training in the Metalworking Industry

PERCENT OF APPRENTICESHIP PROGRAMS WITH FORMAL CLASSROOM INSTRUCTION

Formal Instructions	Percent of Apprentice Programs
No formal classroom instruction given	24%
Formal classroom instruction given	76
	100%

* * * * * * * *

TEACHER OF FORMAL CLASSROOM INSTRUCTION

Formal Instruction Given By	Percent of Apprentice Programs with Formal Classroom Instruction a)
Employees of state vocational education system	46%
Company employee(s) whose only function is training	31
Company employee(s) with other functions in addition to training	40
Instructor from a union	1
Other b)	43

a) Detail adds to more than 100% due to multiple response.

b) Presumably this includes correspondence courses, private trade schools, etc.

Source: Kincaid, Harry V., The Scope of Industrial Training in Selected Skilled and Technical Occupations, Table 21, p. 47, Stanford Research Institute, October, 1966.

The major portion of related training in the maintenance field is devoted to the study of mathematics, electrical subjects, drafting and blueprint reading, general science and shop theory--in that order. As can be seen in Exhibit XVII-A, these five subject areas represent more than ninety percent of the related instruction and varied from a maximum of 22% to a minimum of 12% of total related instruction for the three major maintenance occupations. Mathematics, which represents 22% of the related instruction given to the three major maintenance occupations, ranges from general shop arithmetic through trigonometry and related calculus. Of the training programs considered for all six occupations, only one did not provide for mathematical instruction -- a steel company program for pipefitters. The maintenance classification devoting the largest portion of instructional time (24%) to mathematics is in the field of machinery repairmen; the lowest is in the training of welders, with 16%. It is interesting to note that even those training programs that require an entering trainee to have taken algebra and geometry in high school still devote a large proportion of related instruction to mathematics.

Electrical subjects play a major role in this core of instruction -- representing 20% of total instructional time for the three major maintenance occupations. For the instrument repairman and electrician, this percentage approximates 25%. Most training directors agree that all tradesmen should receive some basic electrical instruction if for no other reason than personal safety.

Exhibit XVII-A

SUBJECTS COVERED IN RELATED CLASSROOM INSTRUCTION FOR THE MAINTENANCE OCCUPATIONS

THE PERCENTAGE DISTRIBUTION OF AVERAGE SUBJECT TIMES *

Subject	Percentage of Total Time Allocated to Subject
Mathematics	22%
Electrical/Electronics/Controls	20%
Blueprint Reading/Drawing	15%
General Sciences	12%
Shop Theory	12%
Others--Safety, Welding, Industrial Relations, Standards, etc.	19%
	100%

* This average distribution is derived from figures for the three major machinery maintenance occupations: the machinery repairman, maintenance electrician, and millwright.

Exhibit XVII-B

SUBJECTS COVERED IN RELATED CLASSROOM INSTRUCTION FOR THE MAINTENANCE OCCUPATIONS

Percentage Distribution of Average Subject Times in the Apprenticeship Programs Studied

Subjects \ Occupation	Machinery Repairman	Maintenance Electrician	Plumber-Pipefitter	Millwright	Instrument Repairman	Welder
Mathematics	24%	25%	18%	18%	19%	16%
General Sciences	12	5	15	18	10	19
Electrical - Power, Electronics, Controls	3	24*	2	7	25*	3
Hydraulics	4	3	4	1	3	1
Mechanics	5	--	--	--	--	--
Shop Theory	27	2	6	7	5	4
Controls/Instruments	--	10	--	--	15	--
Electronics	--	15	--	--	2	--
Blueprint Reading/Drawing	18	7	17	19	5	18
Pyrometry	--	--	--	--	13	--
Pipefitting/Plumbing	--	--	23	--	--	1
Welding	--	--	--	10	--	31
Millwright Theory and Practice	--	--	--	12	--	--
Other - Safety, Welding, Industrial Relations, Standards	7	9	15	7#	5	7#

* Excluding electronics, control

# Excluding welding

The amount of time spent in drafting and blueprint reading subject areas is fairly consistent throughout all maintenance occupations with the exception of instrument repairmen and electricians, who spend only 5% and 7%, respectively, of their time in these areas. Millwrights, machine repairmen, pipefitters, and welders spend 17-19% of their classroom instruction time in drafting and blueprint reading. The ability to sketch is considered essential for most maintenance occupations (See Chapter III). Despite the study findings which indicate that engineering drawing is not required of maintenance workers, this skill is taught to many apprentices, and probably comprises another area of maintanance training in which unneeded training is provided.

A fourth major area of classroom instruction is science, encompassing such subjects as physics, chemistry, characteristics of metals, heat treatment, etc., and accounting for 12% of the time spent in training for the three major maintenance fields. The science instruction given millwrights and pipefitters ranged from 15-20%; whereas, science represents only 5-12% of the training for electricians, instrument and machinery repairmen.

Shop theory constitutes another major area of classroom instruction. It represents 12% of the instruction provided the three major maintenance occupations. Considered to be the most important area of study for machinery repairmen, it accounts for 27% of the instruction provided for that field. Instruction in shop theory is allocated 2-7% of classroom training time for the other maintenance occupations considered.

Other subjects taught during classroom instruction are welding, safety, industrial relations, and standards. Some companies placed importance on industrial relations and provided courses in communications, psychology, writing, and economics. For example, Cleveland Twist Drill Company felt this area of sufficient importance to devote almost 25% of their classroom training time to instruction in these fields. However, most companies offered only one or two courses in this area.

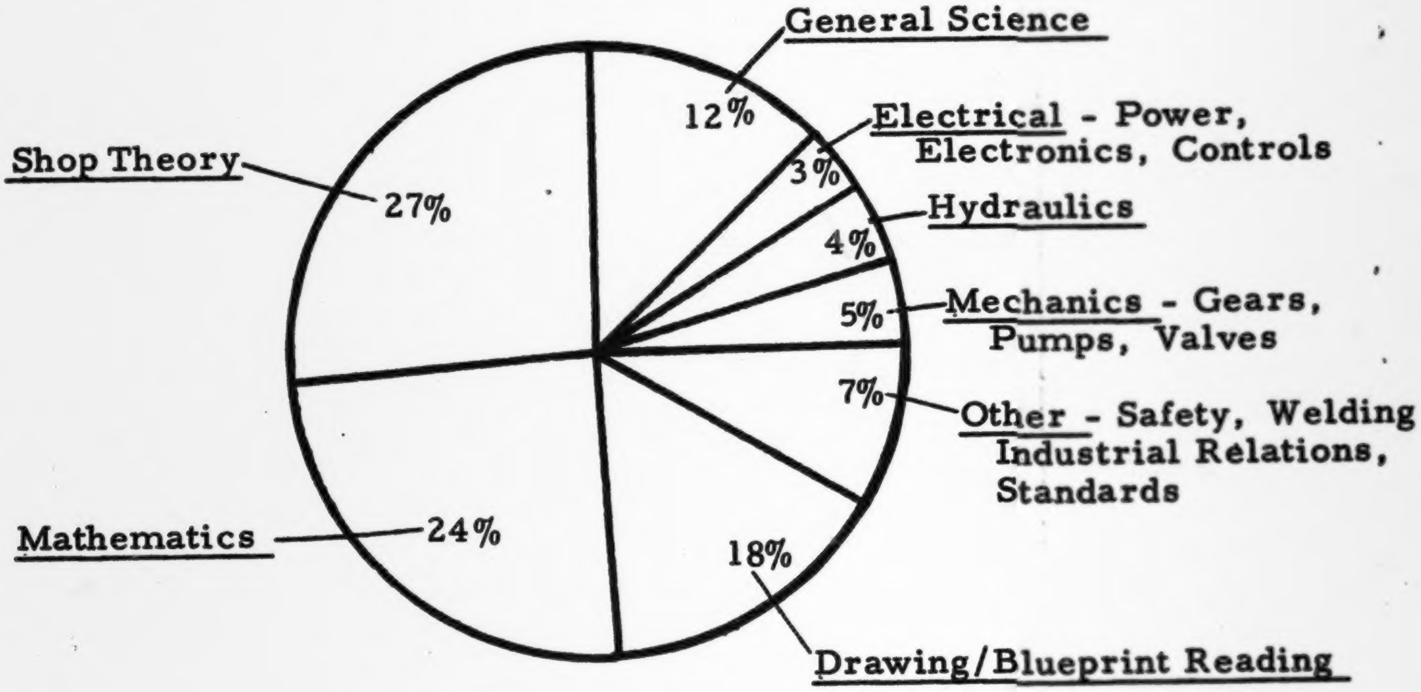
The percentage distribution of classroom training time by subject for each of the programs of related instruction examined during the study in

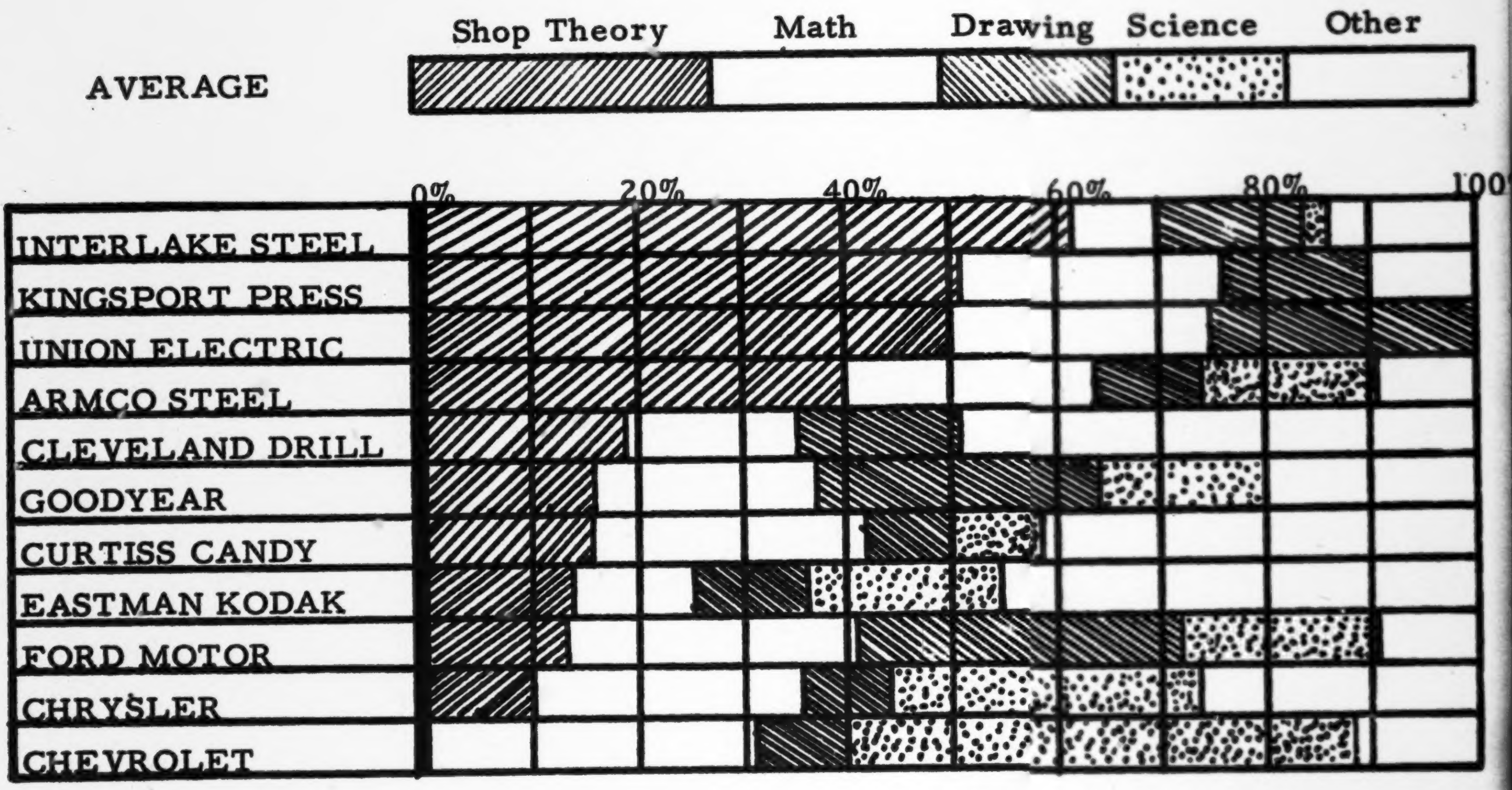
Exhibit XVIII

MACHINERY REPAIRMAN

Related Classroom Instruction--
Percentage of Time Spent by Subject

Typical Percentage Time Distribution in Firms Studied





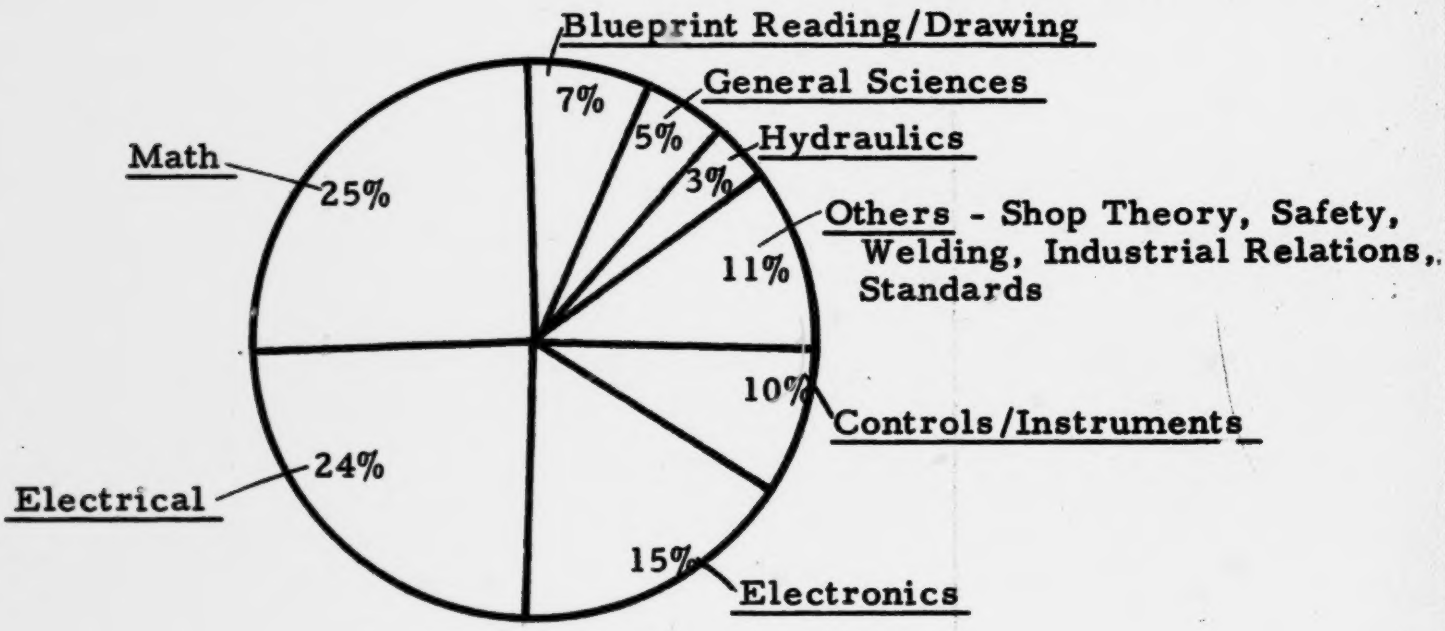
Source: Midwest Institute for Research & Training

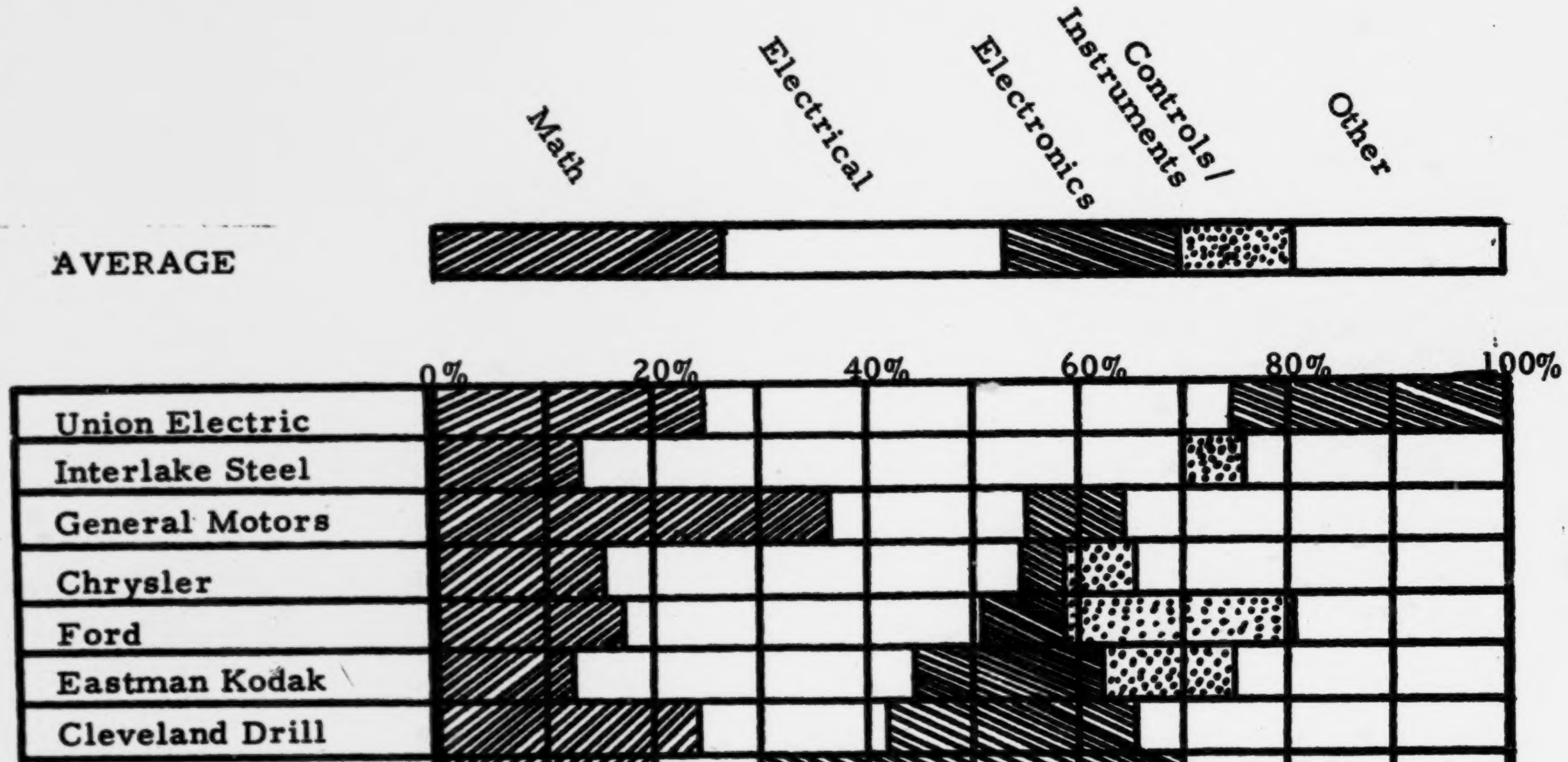
Exhibit XIX

MAINTENANCE ELECTRICIAN

Related Classroom Instruction

Average Percentage Time Spent by Subject in Firms Studied





Source: Midwest Institute for Research & Training

the machinery repairman and maintenance electrician occupations is shown in Exhibits XVIII and XIX, respectively. As was indicated earlier, the amount of time devoted within each trade classification to the various subject areas varies enormously from company to company. In most cases, this variation appears to have little relationship to differences in the content of the maintenance job itself, but apparently reflects differences in the importance companies place on generalized versus specialized training and fundamental versus applied subject areas.

* * * * * * *

From the discussion of existing machinery maintenance training programs presented in this segment of the report, several important conclusions can be drawn:

1. Despite the fact that there is widespread agreement among plant engineers, maintenance supervisors and industrial training directors on the need for better and more effective maintenance training, most of this training is presently provided by informal on-the-job training, often without any direct control or supervision provided in this training.

2. In a substantial proportion of the formal maintenance training programs examined during this investigation, the time devoted to on-the-job training appears to be more than can be reasonably justified; a 2-3 year formal training program may be more adequate for most maintenance occupations than the 4-year program that is most commonly found in industry today.

3. One additional area of related classroom instruction -- engineering drawing and drafting, which appears in many formal maintenance programs, also apparently is unnecessary for most maintenance occupations.

4. Considerably more research and investigation is needed to evaluate the extent to which on-the-job training and classroom instruction are most effective in imparting the required knowledge and skills in each of the major subject areas encompassed by machinery maintenance training.

CHAPTER FIVE

FUTURE CHANGES IN MAINTENANCE TRAINING AND SKILL REQUIREMENTS

FUTURE CHANGES IN MAINTENANCE TRAINING AND SKILL REQUIREMENTS

The final aspect of this research study is concerned with assessing the impact which changes in the design and construction of production machinery and in their maintenance requirements will have on the training and skill requirements of industrial machinery maintenance workers in the future. The problem of obsolescence of training and skills is not unique to the field of machinery maintenance. It encompasses all areas of occupational training, ranging from engineers to office workers and from corporate management to machine operator, and presents those concerned with instituting training programs with a frustrating dilemma --- individuals who are trained for today's occupational needs possibly will not be able to meet tomorrow's changing occupational requirements; however, persons trained specifically for tomorrow's occupational needs may be unable to compete in today's labor market.

The primary objective of this section of the report is to define some of the major changes that are likely to take place in the field of machinery maintenance during the next 10 years and to indicate their likely impact on future training and skill requirements of individuals employed in this field. Hopefully, this information can be utilized by training directors and others to ensure that the "basic training" necessary to permit maintenance workers to adapt to these changes will be included in present maintenance training programs.

I. THE RATE OF CHANGE IN PERSPECTIVE

Before evaluating specific changes that are expected to have an impact on the field of machinery maintenance during the next decade, it is important to have some understanding of the time factors which control the rate at which innovations are incorporated into production machinery and are subsequently translated into new demands on maintenance and repair. From an examination of a number of recent technological developments now finding widespread application in production machinery, it is evident that manufacturers of this equipment are not quick to incorporate new developments into the design and engineering of their equipment. For example, hydraulic servo systems were developed and used extensively on aircraft built during World War II, but these hydraulic servo systems were not adopted by machinery manufacturers for another 10-15 years. Similarly, solid-state electronics was introduced commercially in 1951, but did not begin to find its way into production machinery for 8-10 years and is still beyond the sophistication of a large number of companies that supply this machinery. A historical study by Professor Mansfield at Carnegie Institute of Technology (34) of 12 major industrial innovations indicated that in most instances a minimum of 10 years elapsed before all major firms in an industry introduced these innovations and, in a majority of the cases, this time-period was 20 years or more. Although there is strong evidence to indicate that the rate of change is accelerating in our modern industrial society, it is unlikely that the time required to introduce new concepts into production machinery will be shortened appreciably in the foreseeable future.

A second factor which inhibits the rate at which the training and skill requirements of machinery maintenance workers will be affected by changes in machinery concepts is the inventory of older machinery in existence in industry at any point in time. Rarely, if ever, will industry immediately replace its entire inventory of production machinery when equipment incorporating new concepts is introduced. More commonly, industry purchases new production machinery to enlarge its production capacity and to replace its most obsolete equipment. As a result, even when major new machinery concepts are introduced, they diffuse at a relatively slow rate. One example of this slow rate of diffusion is provided by an inventory of machine tools conducted by American Machinist (42) in 1963 which indicated that 64% of industry's inventory of this type of production machinery is more than 10 years old and 21% is more than 20 years old.

The impact of this relatively slow rate of change in industry's inventory of production machinery to maintenance training and skill requirements is quite evident. An individual who enters industry's machinery maintenance workforce today is likely to spend most of his time working on yesterday's production machinery --- equipment that is 5, 10 or more years old. Furthermore, when machinery manufacturers do introduce new concepts and new technologies into their equipment, they ordinarily provide the purchaser of this equipment with extensive technical service and support during the period of time required to assimilate this machinery into the plant's production and maintenance operations. This technical support often includes providing stand-by factory maintenance personnel and conducting special training courses for the plant's maintenance and production workers. In some instances, this technical support may extend over a period of 1-3 years.

The net result of these factors is that maintenance training and requirements do not have to lead nor even keep abreast of technological change. Considering the time period required for new developments to be incorporated in production machinery and equipment, the time period provided by machinery suppliers in supplying extensive technical support while this new equipment is being assimilated and the time period which transpires before these new technologies and new concepts become an important segment of maintenance activities, it appears that maintenance training and skill requirements can readily lag new developments by 5 years or more.

Despite this time-lag, it will be necessary for the machinery maintenance field to continuously adapt its training requirements for new workers to new concepts and new technologies and to upgrade the skills and knowledge of older maintenance workers to these new requirements. Therefore, it is important to examine new developments relating to the machinery maintenance field and to assess, to the extent possible, the implications they hold for maintenance training. Hopefully, this foresight will enable training directors in institutions and industry to provide maintenance workers with the basic knowledge and skills that will enable them to adapt to the changes that do occur at some time in the future.

II. TECHNOLOGICAL DEVELOPMENTS

Of all the forces acting upon the machinery maintenance field, technology will undoubtedly have the greatest impact during the foreseeable future. Ten years ago, the use of electronics was virtually unknown in production machinery and equipment; today, with numerical control, proximity switches and other electronic devices becoming increasingly important in the operation and control of production machinery, electronic maintenance is becoming an integral part of industry's maintenance activities. Other new technological developments are gaining in importance and will be altering the maintenance requirements of industry in the future.

There are an almost unlimited number of new developments that might be cited as having some potential impact on maintenance training and skill requirements. However, several technological developments stand out as having major implications for machinery maintenance during the next 5-10 years and, therefore, are worthy of mention in this report.

A. Automated Production Systems

Despite the fact that "automation" has been a by-word in our economy for the last 30 years, automated production systems still remain a relatively small part of industry's total production capability. At the present time, it is estimated that automated production equipment accounts for approximately 10% of the total productive capacity of industry and is heavily concentrated in the automotive, appliance, and other consumer-goods industries. As the economic base of this country continues to grow in the future (due to population increases and economic factors), automation concepts will find increasing application throughout industry. One projection indicates that by 1980, automation-type production machinery will increase from its present level of 10% to 17% of total production capacity --- an increase of 70% during this period.

Although it is evident from these estimates that the problems of automation are not of such crisis proportions as some observers have indicated, this expansion of automated production concepts into new areas of manufacturing are important for a number of reasons:

1. Since this type of production machinery is normally "dedicated" to a single manufacturing task rather than being designed for general-purpose manufacturing activity, the equipment is typically composed of complex mechanical, hydraulic, pneumatic, electrical and electronic systems, incorporating advanced concepts in each of these fields.

2. The coordination and control of this complex equipment generally requires the use of sophisticated instrumentation and control devices (including electronic computers in some of the most modern equipment) that is ordinarily not found in other types of production machinery.

3. Production rates on this type of equipment are often considerably higher than those of most industrial machinery which results in an increase in the speed of individual machinery components and makes such factors as the inertia of moving parts, vibration control and time-delays between initiation and reaction of components critical factors in the maintenance of this equipment.

4. "Downtime" is extremely costly and, as a result, a premium is placed on maintenance "troubleshooting" and diagnostic skills to reduce lost production time to the lowest level possible.

The net result of these factors is to increase the relative importance of machinery maintenance in these automated production applications in comparison to most manufacturing operations. Maintenance workers in these plants must be better trained, have more sophisticated technical knowledge and capability, be well versed in the principals of troubleshooting and generally be above the level of most machinery maintenance workers.

B. New Advances in Electronic Controls

Until very recently, machinery controls were primarily confined to relatively simple "relay and limit switch" systems which are electro-mechanical in nature. The major deterrent to the widespread use of electronic control devices in most production machinery has been the inability of these electronic controls to function reliably in the relatively hostile environment (i.e., heat, dirt, vibration, etc.) in which this equipment normally operates. However, the development of low cost transistors and other solid-state devices has removed many of these obstacles and has made electronic controls feasible, both technically and economically. The most recent advance in electronics, integrated circuits, is likely to make electronic machinery controls even more attractive.

They are more reliable than solid-state electronic devices under the conditions found in most manufacturing plants and the projected cost of these devices will encourage their use in complex, sophisticated electronic control systems for production machinery and equipment.

The obvious impact of solid-state and integrated circuit controls on machinery maintenance is the requirement for electronic knowledge and skills by electrical maintenance workers. Since there is very little over-lap between electronic and electrical concepts and training, the upgrading of maintenance electricians into electronic repairmen involves almost complete retraining and is often resisted by older maintenance workers.

A partial answer to this problem --- modular design --- has been developed and is now widely used in the electronic numerical controls. With this concept, electronic circuitry is designed in modules which can quickly be removed and replaced with new modules. When a malfunction has been detected in one of these modules, the entire module is removed and a new one substituted for it, enabling the equipment to be immediately returned to operating condition. The defective module is then sent to a specialist in electronic repair who then isolates the exact cause of the trouble and makes the necessary repairs.

It is expected that modular design will become an integral part of electronic controls in most production machinery in the next 3-5 years (particularly as integrated circuits move into this field) and will be reflected in the maintenance requirements of this equipment. The primary impact will be to concentrate the knowledge and skills required to repair these electronic controls in a few maintenance specialists within the plant; the remainder of the electrical maintenance workforce will have to be skilled in electronic control troubleshooting and diagnosis, but will not need the high level of training required of the maintenance workers who do the actual repair of these controls.

C. Hydraulic Power and Control Systems

Hydraulics are not new to the design and construction of production machinery, but, in the past, its role has been confined to relatively simple, low pressure (100-300 psi) applications, involving hydraulic power cylinders. As indicated previously, hydraulic servo technology developed during World War II is now finding its way into the design of production machinery. This hydraulic servo technology utilizes high pressures (3,000-10,000 psi) and involves a degree of technical skill and knowledge far greater than is needed with conventional low pressure systems. It requires attention to such problems as contamination of fluids, shock and vibration, potential safety hazards, precise tolerances, complex valve and switching systems, and hydraulic motors and actuators. At the present time, this hydraulic servo technology is beyond the capabilities of most mechanical repairmen and millwrights in industry's maintenance workforce, but the growing use of hydraulic servo systems will probably require that most large plants have several hydraulic repairmen in their maintenance departments and will certainly require most mechanical repairmen and millwrights to have a higher level of knowledge and skill in the field of hydraulics than is now commonplace.

Another new development is emerging in the field of hydraulics, fluidic controls, and is likely to have an effect on industry's maintenance requirements in the foreseeable future. Fluidic control systems are analogous to electronic control systems except that the system is controlled by the flow of a gas or a liquid rather than a flow of electrons. Although slower in operation than electronic controls, fluidic control systems are much more reliable under conditions where excessive heat, vibration or contamination make electronic control systems unreliable or when safety considerations make the use of electronic controls hazardous. The exact role which fluidics will play in industry's maintenance requirements in the future is indeterminant at the at the present time, but it may be another area of hydraulics in which industry's machinery maintenance workforce will require new training and skills.

D. Increasing Speed, Size and Complexity of Production Machinery

The increasing speed, size and complexity of production machinery and equipment is certain to have some impact on the knowledge and skill requirements of industrial maintenance workers. As the operating speed of this machinery increases, new maintenance requirements are created --- sleeve and journal bearings are displaced by ball and roller bearings; inertia and vibration problems become increasingly more important, the action of critical components also increase and "cranes" often have to be substituted for "muscle" in handling some of these components.

The growing complexity of production machinery is creating maintenance problems which are difficult to assess, but which are becoming increasingly important to industry. The nature of this problem can probably best be illustrated by a typical example of one of the most frequent problems that arise. If a limit switch has an expected life of one million cycles and 10 of these switches are installed on a machine where they function once per second, it can be expected that every 2-3 hours one of these limit switches will have to be replaced due to a failure. In a modern production operation, such a condition cannot be tolerated and preventative maintenance procedures have to be instituted. This concept of anticipating problems and taking corrective action before a failure occurs is becoming a growing portion of industry's machinery maintenance activities.

It is difficult to determine the specific impact which these technological changes will have on maintenance training and skill requirements. However, it is apparent that more formal training in maintenance concepts and principles will be required of maintenance workers in order to cope with these problems.

III. CHANGES IN MAINTENANCE FUNCTIONS

In the past, the maintenance procedures within a manufacturing operation have largely been independent of the type of management controls and measurements that are widely applied to the other facets of the production process. The extent of this void in management control is indicated by a recent survey by Factory magazine (28) which indicated that . . .

. . . 70% of the maintenance departments do not know or keep accurate records of downtime costs and charges.

. . . 70% do not compile maintenance labor and material cost data.

. . . only 20% have a working preventive maintenance program.

. . . less than 10% use systems analysis techniques to determine maintenance crew size and to control their inventory of spare parts.

As problems in traditional areas of management concern are being resolved, emphasis is now being shifted toward many of these long-neglected maintenance problems. One result of careful analysis of maintenance activities is likely to be a restructuring of functions within the maintenance workforce. The present procedure for coping with a machinery maintenance problem that occurs in a typical manufacturing plant is shown in Exhibit XX. As this chart indicates, the individual steps in this maintenance procedure are all normally performed by the same maintenance worker (i.e., mechanical repairman, millwright or electrician). He is responsible for the identification of the cause of failure, the decision as to the action that should be taken to eliminate the cause of failure, and on-site repair of the problem. To accomplish all of these individual maintenance functions, the maintenance worker must have a high degree of knowledge and skills in each of the following areas:

. . . diagnostic and troubleshooting procedures.

. . . a detailed working knowledge of the particular machine being repaired.

. . . specialized knowledge in a specific area of machinery maintenance.

. . . manipulative and mechanical skills needed to effect the actual repair or replacement.

From the investigations undertaken during this research study, it appears that in the future (perhaps by 1975), a different type of machinery maintenance procedure will be in operation in industry. As indicated In Exhibit XXI , this procedure will be broken into three separate functions that will be performed by three different types of individuals within the maintenance workforce. The first of these functions --- identification of the cause of failure and determination of the actions to be taken to return the equipment

Exhibit XX

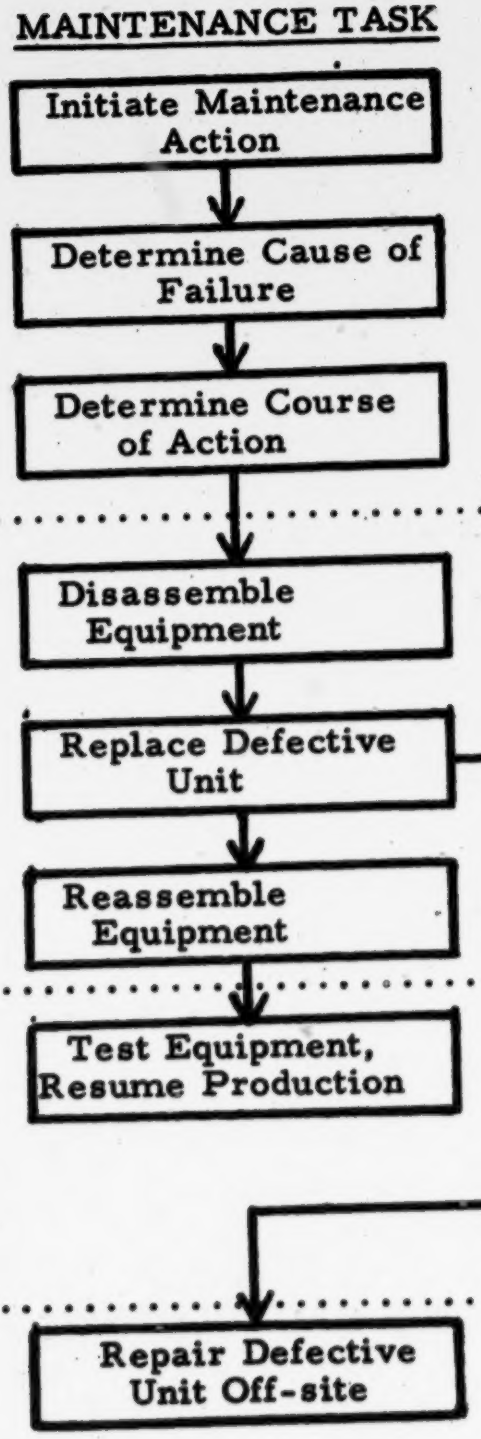
CHARACTERISTICS OF INDUSTRY'S PRESENT MAINTENANCE PROCEDURES AND FUNCTIONS

MAINTENANCE TASK	SKILLS REQUIRED	PERSONNEL INVOLVED
Initiate Maintenance Action → Determine Cause of Failure → Determine Course of Action	. Troubleshooting & diagnostic ability . Schematic diagrams . Instrumentation . Basics of many technologies	Machinery Maintenance Specialist
→ Disassemble Equipment	. General tools & techniques	Machinery Maintenance Specialist
→ Repair Equipment On Site	. High degree of knowledge in a specific technology	Machinery Maintenance Specialist
→ Reassemble Equipment	. General tools & techniques	Machinery Maintenance Specialist
→ Test Equipment; Resume Production	. Instrumentation . Schematic diagrams . Basics of many technologies	Machinery Maintenance Specialist

Source: Midwest Institute for Research & Training

Exhibit XXI

CHARACTERISTICS OF INDUSTRY'S FUTURE MAINTENANCE PROCEDURES AND FUNCTIONS


MAINTENANCE TASK
Initiate Maintenance Action
Determine Cause of Failure
Determine Course of Action
Disassemble Equipment
Replace Defective Unit
Reassemble Equipment
Test Equipment, Resume Production
Repair Defective Unit Off-site

SKILLS REQUIRED	PERSONNEL INVOLVED
. Troubleshooting & diagnostic ability . Schematic diagrams . Instrumentation . Basics of many technologies . Accurate observation & recording of data on failure cause & cure	Machinery Maintenance Technician
. General tools & techniques . Knowledge of specific equipment being repaired	Machinery Maintenance Repairman
. Instrumentation . Schematic diagrams . Basics of many technologies . Accurate observation & recording of data on failure cause & cure	Machinery Maintenance Technician
. High degree of knowledge in a specific technology	Component Repair Specialist

Source: Midwest Institute for Research & Training

to normal operation --- will be performed by a maintenance technician. This technician (See Chapter III) will be trained in all aspects of machinery technology and in the principles and procedures of troubleshooting. Furthermore, his duties will include much of the "follow-up" that is required to provide a detailed assessment of the particular cause of the problem and to ensure that an accurate accounting is made of downtime, maintenance costs and other information that will become an increasingly important aspect of industry's control of its maintenance operations.

The second group of functions, involving the disassembly of the equipment, the replacement of the defective unit and the reassembly of the equipment will be performed by a general maintenance worker. This individual will be highly trained in manipulative and mechanical skills, but because he does not have to identify the source of the failure, he will probably not be as highly skilled as the typical maintenance worker now in industry. However, some degree of maintenance specialization (i.e., mechanical vs. electrical) will probably continue to exist at this level primarily due to union contract restrictions on maintenance activities.

The third function in this maintenance procedure --- off-site repair --- will result from the modular construction concept that was discussed previously. With modular construction, the unit containing the failure will be removed and replaced with a working unit and then sent to a maintenance specialist in the particular technology involved where repairs will be made under properly controlled conditions and with specialized equipment. This repair specialist will not only have an overall level of skill and training slightly above that of present maintenance workers, but will probably have a greater knowledge of analytical instrumentation. Furthermore, because of his high degree of specialization, this type of maintenance worker will have a considerably higher level of practical knowledge and experience in his specialty than his present counterpart in industry.

The specific impact which this change in maintenance functions will have on maintenance training programs was difficult to assess during this investigation. However, except for the maintenance technician, it appears that this realignment of maintenance functions can be accommodated within the scope and framework of existing machinery maintenance training programs. As indicated previously, the maintenance technician will probably require two-year post-secondary school training as well as specialized industrial training in troubleshooting practices and procedures.

* * * * *

The objective of this section of this report was to outline to the extent possible some of the developments that are likely to affect machinery maintenance training and skill requirements in the foreseeable future, with the hope that this information would be useful to school and industry training directors in organizing, planning, and instituting maintenance training programs. Based on this discussion, it appears that three important changes will be occurring in industry's future maintenance requirements:

1. Electronics and hydraulics will become increasingly important areas of technical knowledge and training.

2. The role of diagnostic and troubleshooting skills and training will grow in importance in machinery maintenance occupations.

3. The present procedure in which one individual performs all steps in maintenance and repair of equipment failures will eventually be broken into three separate functions --- diagnosis, replacement and repair --- that will be performed by different types of individuals having different levels of training and skills within the maintenance workforce.

CHAPTER SIX

RECOMMENDATIONS

RECOMMENDATIONS

As indicated previously in this report, the field of industrial machinery maintenance is particularly suitable for occupational training. The characteristics of the labor market for machinery maintenance --- its size, distribution within our economy, rate of growth and earnings potential --- all suggest that persons trained in this field can expect to become productive members of our industrial workforce. It is an area in which training is becoming increasingly more critical, yet almost no formal training is presently being provided by schools and institutions despite the fact that certain facets of this training appear to be compatible with the type of occupational training that is best provided by these organizations. Even industry's participation in maintenance training leaves much to be desired. Most of this training presently is being provided through informal, on-the-job training and many of the formal training programs that do exist are open to challenge concerning the amount of time spent in training and the subject matter included in these programs.

From these comments, it is evident that a number of problems presently exist which must be overcome before occupational training in this field can be expected to supply industry's growing need for adequately trained machinery maintenance workers. During the course of this investigation, it was possible not only to evaluate the magnitude of the problems facing the field of maintenance training, but also able to identify steps that could be taken to resolve many of these problems. In certain instances, the Midwest Institute for Research and Training has already been able to act as a catalyst to initiate action by industrial and private organizations to overcome some of these problems.

I. PROVIDE ADEQUATE TRAINING MATERIALS

Undoubtedly, the most critical problem encountered in the entire field of machinery maintenance training is the lack of adequate training materials such as text books, course outlines, training aids, etc. Although some published text books do exist, they are primarily limited to the basic training subject areas (e.g., shop math, blueprint reading, basic electricity, etc.) and, in many cases, are only marginally applicable to maintenance training. Therefore, any organization that is interested in establishing a maintenance training program is faced with the almost insurmountable task of having to develop training materials for these programs. As a result, many schools, training institutions and companies that have a vested interest in maintenance training are discouraged from initiating training programs in this field.

There are a number of steps that could be undertaken to alleviate this shortage of training materials. Perhaps the publication of this report will stimulate the interests of publishers of training materials to expand the scope of their activities in this field. Another solution might be for the U.S. Office of Education to underwrite the cost of preparing these training materials. However, it is our opinion that the most effective and immediate answer to this problem can and should be provided by private industry.

During these investigations, it was discovered that a number of large companies (e.g., Ford Motor Company, Du Pont, American Airlines, etc.) have already developed maintenance training materials for their own use. Some of these materials are oriented toward their particular company requirements (i.e., aircraft maintenance), but a large portion of these materials appear to be directly applicable to most machinery maintenance training programs. Further discussions with some of these companies revealed that they would be willing to make these training materials available to other companies and to training institutions, but they were unwilling to underwrite the costs of disseminating these materials to interested organizations.

Based on these findings, the Midwest Institute for Research and Training has developed the concept of a "Clearinghouse for Industrial Training Materials." The objective of this proposed organization (which is described in more detail in Appendix G) is to acquire, inventory, evaluate, index and disseminate these maintenance training materials to schools, training institutions, companies and other organizations that are interested in establishing training programs in the machinery maintenance field. The primary reason for utilizing a vehicle such as the Clearinghouse to provide adequate training materials in the machinery maintenance field is that it could make available a vast reservoir of training materials (representing an initial investment of an estimated $10-15 million) without the time delay that is normally required to develop such materials. At the present time, the Clearinghouse proposal is under consideration by the Ford Foundation and by "Plans for Progress" and it is hoped that the initial funding required to organize the Clearinghouse can be obtained from those organizations or from interested companies in industry.

II. DISSEMINATE INFORMATION ABOUT TRAINING REQUIREMENTS

Although plant engineers, maintenance supervisors and training directors have a general knowledge and understanding of maintenance training requirements, detailed information on subjects to be included in such a training program and the amount of time required to impart this training is largely unavailable. The publication of this report will provide a major step toward resolving this problem. To further disseminate the findings of this investigation, the American Institute of Plant Engineers and the Mid-West Institute for Research and Training are jointly planning to sponsor a nationwide conference on maintenance training and skill requirements within the next six to nine months. Hopefully, this major conference can be followed by a series of regional training seminars in the major industrial areas of the country to further disseminate this information to smaller companies and to local institutional training groups.

The major question which remains unanswered in this subject of machinery maintenance training requirements concerns the role which classroom instruction and on-the-job training should play in providing this training. At the present time, on-the-job training is utilized to provide the vast majority of this training, particularly in complex subject areas. Yet, the airlines and the aerospace companies have demonstrated that classroom training involving well organized instruction, adequate training aids, and simulation devices has a far greater capacity to impart industrial training and skills than is presently being utilized. Furthermore, the overall cost of this classroom training may be considerably lower than that of the on-the-job training that is presently being provided. This entire subject of classroom vs. on-the-job training appears to be a fruitful area for further research and investigation by the Division of Adult and Vocational Research of the U.S. Office of Education.

III. ESTABLISH A CORE CURRICULUM IN THE VOCATIONAL SCHOOLS

As indicated in Chapter IV of this report, machinery maintenance training programs are almost non-existent at the secondary school level at the present time. Nevertheless, it appears that certain aspects of machinery maintenance training are compatible with the training capabilities of vocational and adult training programs found in most of these schools. However, it is suggested that vocational training should not be limited to the machinery maintenance field, but should be broadened to encompass a host of other maintenance-related occupations --- ranging from air conditioning mechanic to appliance serviceman and from automotive mechanic to telephone repairman.

The investigations undertaken during this study suggest that most of the basic maintenance training subjects and some of the fundamental specialized training subjects could be incorporated in a single "core" curriculum that would be applicable to nearly all of the maintenance-related occupations listed in Appendix C. The subject areas that would be included in this "core" curriculum would be dependent on the capabilities of the individual vocational training programs. Most vocational schools would probably limit their training activities to the basic maintenance training subjects plus a selected number of the fundamental specialized training subjects; more comprehensive vocational training programs such as are now being established in area vocational schools would probably enlarge the subject areas that would be encompassed by their training programs.

Since more than five million persons are presently estimated to be working in these maintenance-related occupations, it would appear that the number of persons who could benefit from this type of training would make it a particularly attractive field of training to vocational schools located in industrial centers throughout the country. Appendix H contains a list of the subject areas which might be included in such a "core" maintenance training curriculum; however, further investigation should be undertaken to determine the applicability of these subject areas to all of the maintenance-related occupations and to identify other subjects that might be included in this curriculum. The determination of the feasibility of developing a common "core" curriculum for maintenance-related occupational training would appear to be the type of research study that might be undertaken by the Division of Adult and Vocational Research.

One other obstacle inhibiting the establishment of machinery maintenance training programs in vocational schools has been the lack of information concerning employment and earning opportunities in this field. To a large extent this lack of information is responsible for the present notable lack of interest exhibited by vocational schools in machinery maintenance training. The dissemination of the results of this research study through the proposed nationwide and regional conferences on machinery maintenance training and the anticipated publication of several magazine articles in various publications should help to acquaint educators in vocational schools with the potential opportunities in this field. However, it is doubtful if these efforts will provide the "exposure" that will be necessary to arouse widespread interest on the part of vocational schools and their students in the field of machinery maintenance training. Therefore, it is strongly recommended that the findings of this investigation be utilized to develop comprehensive career guidance materials which can then be distributed directly to vocational training schools and institutions throughout the country.

IV. DEVELOP TRAINING PROGRAMS AT THE POST-SECONDARY SCHOOL LEVEL

The opportunities for machinery maintenance training activities in junior colleges and other post-secondary training institutions appear to be limited by the costs and equipment requirements associated with providing this training beyond the subject areas outlined previously for vocational training schools. To provide sophisticated training in most of the advanced specialized training subjects would appear to be beyond the capabilities of most post-secondary schools and other training institutions. However, a major opportunity for maintenance training at this level will occur with the emergence of the maintenance technician as a member of industry's maintenance workforce. This maintenance technician will require levels of technical knowledge and training which are considerably beyond ordinary vocational school capabilities and which are particularly suitable for post-secondary school training institutions.

At the present time, the demand for maintenance technicians has not reached a level where there is a widespread need for this type of training, and this condition will probably continue to exist for the next 3-5 years. However, it is expected that the demand for maintenance technicians will increase steadily during this period and more and more junior colleges will be instituting programs designed to provide industry with these maintenance technicians. The work recently completed on the development of an electromechanical curriculum at Oklahoma State University should provide an excellent starting point for the development of training programs for these maintenance technicians.

V. RE-EXAMINE FORMAL MAINTENANCE TRAINING PROGRAMS

The evaluation of formal machinery maintenance training programs in industry indicates that a major re-examination of these programs should be undertaken. This evaluation indicated that ...

- ... most of these formal training programs examined are based on a standard 4-year (8,000 hour) training schedule; yet, it appears that a 2-3 year training schedule (4,000-6,000 hours) would be much more appropriate for this type of training.
- ... many of these programs provided training in subject areas which appear to be unnecessary for machinery maintenance workers.
- ... a large number of individuals enter the machinery maintenance workforce from production jobs and other sources which cause them to be excluded from normal apprenticeship training programs because of their age.

It would appear that a thorough reassessment of formal machinery maintenance training programs could eliminate a substantial expenditure of time and effort that is presently being wasted in providing unneeded training to individuals enrolled in these programs. Furthermore, this reassessment may help to eliminate one of the major problems in formal training programs --- the individual who quits before the program has been completed --- by reducing the time required to complete the program and by making the subject material more closely attuned to actual maintenance requirements. Also, if a mechanism could be established by which older workers could be introduced into apprenticeship programs, an opportunity would be provided for production workers and others to obtain the training that will enable them to enter industry's machinery maintenance workforce with the knowledge and skills which they will need to succeed in this field.

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This portion of the report has outlined the most significant problems in the maintenance training field, and various steps which should be undertaken to resolve the most critical problems facing this field. It has also described efforts that have already been initiated in this regard as a by-product of this investigation. Hopefully, the results and recommendations of this study will be utilized to increase the amount of machinery maintenance training that is presently being provided and to raise the level of effectiveness of maintenance training programs now in existence. The extent to which these two objectives can be obtained will largely determine the contribution which this research study has made to the continued growth of our nation's economy and to providing individuals with the training and skills that will enable them to become useful, productive members of our industrial society.

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